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CAPE TRINITY ON THE SAGUENAY.

A salient point of Laurentian Gneiss, on an old fiord of Pliocene erosion (p. 99).

(From a Photograph by Henderson.)

SOME SALIENT POINTS

IN THE

SCIENCE OF THE EARTH

BY

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WITH FORTY-SIX ILLUSTRATIONS



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PREFACE.

THE present work contains much that is new, and much in correction and amplification of that which is old; and is intended as a closing deliverance on some of the more important questions of geology, on the part of a veteran worker, conversant in his younger days with those giants of the last generation, who, in the heroic age of geological science, piled up the mountains on which it is now the privilege of their successors to stand.

J. W. D.

Montreal 1893.



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TABLE OF GEOLOGICAL HISTORY.

NON-GEOLOGICAL readers will find in the following table a condensed explanation of the more important technical terms used in the following pages. The order is from older to newer.

GREATER PERIODS.	SYSTEMS OF FORMATIONS.	CHARACTERISTIC FOSSILS.	
ARCHÆAN OR EOZOIC	Pre-Laurentian Laurentian	Protozoa	Protophyta
PALÆOZOIC	Huronian Cambrian Cambro-Silurian* Silurian† Devonian Carboniferous Permian	Crustaceans Molluscs Worms Corals, etc. Fishes Amphibians	Algæ Cryptogamous and Gymnospermous Plants.
MESOZOIC	Triassic Jurassic Cretaceous	Reptiles Birds Earliest Mammals.	Pines and Cycads Trees of modern types.
KAINOZOIC OR TERTIARY	Eocene Miocene Pliocene Pleistocene Modern	Higher Mammals of extinct forms Recent Mammals and Man.	Modern Plants.

* Ordovician of Lapworth. † Salopian of Lapworth.



THE STARTING-POINT.

DEDICATED TO THE MEMORY OF

PROF. ROBERT JAMESON,

OF THE UNIVERSITY OF EDINBURGH, MY FIRST TEACHER IN GEOLOGY, WHOSE LECTURES I ATTENDED, AND WHOSE KIND ADVICE AND GUIDANCE I ENJOYED, IN THE WINTER OF 1840–1841.

HEADLANDS AND SPURS—POPULAR PAPERS ON LEADING TOPICS—REVISITING OLD LOCALITIES—DEDICATIONS—GENERAL SCOPE OF THE WORK

CHAPTER I.

THE STARTING-POINT.

AN explorer trudging along some line of coast, or traversing some mountain region, may now and then reach a projecting headland, or bold mountain spur, which may enable him to command a wide view of shore and sea, or of hill and valley, before and behind. On such a salient point he may sit down, note-book and glass in hand, and endeavour to correlate the observations made on the ground he has traversed, and may strain his eyes forward in order to anticipate the features of the track in advance. Such are the salient points in a scientific pilgrimage of more than half a century, to which I desire to invite the attention of the readers of these papers. In doing so, I do not propose to refer, except incidentally, to subjects which I have already discussed in books accessible to general readers, but rather to those which are imbedded in little accessible transactions, or scientific periodicals, or which have fallen out of print. I cannot therefore pretend to place the reader on all the salient points of geological science, or even on all of those I have myself reached, but merely to lead him to some of the viewing-places which I have found particularly instructive to myself.

For similar reasons it is inevitable that a certain personal element shall enter into these reminiscences, though this autobiographical feature will be kept as much in the background as possible. It is also to be anticipated that the same subject

may appear more than once, but from different points of view, since it is often useful to contemplate certain features of the landscape from more than one place of observation.

To drop the figure, the reader will find in these papers, in a plain and popular form, yet it is hoped not in a superficial manner, some of the more important conclusions of a geological worker of the old school, who, while necessarily giving attention to certain specialties, has endeavoured to take a broad and comprehensive view of the making of the world in all its aspects.

The papers are of various dates; but in revising them for publication I have endeavoured, without materially changing their original form, to bring them up to the present time, and to state any corrections or changes of view that have commended themselves to me in the meantime. Such changes or modifications of view must of necessity occur to every geological worker. Sometimes, after long digging and hammering in some bed rich in fossils, and carrying home a bag laden with treasures, one has returned to the spot, and turned over the *débris* of previous excavation, with the result of finding something rare and valuable, before overlooked. Or, in carefully trimming and chiselling out the matrix of a new fossil, so as to uncover all its parts, unexpected and novel features may develop themselves. Thus, if we were right or partially right before, our new experience may still enable us to enlarge our views or to correct some misapprehensions. In that spirit I have endeavoured to revise these papers, and while I have been able to add confirmations of views long ago expressed, have been willing to accept corrections and modifications based on later discoveries.

In the somewhat extended span of work which has been allotted to me, I have made it my object to discover new facts, and to this end have spared no expenditure of time and labour; but I have felt that the results of discoveries in the

works of God should not be confined to a coterie, but should be made public for the benefit of all. Hence I have gladly embraced any opportunities to popularise my results, whether in lectures, articles, popular books, or in the instruction of students, and this in a manner to give accurate knowledge, and perhaps to attract the attention of fellow-workers to points which they might overlook if presented merely in dry and technical papers. These objects I have in view in connection with the present collection of papers, and also the fact that my own pilgrimage is approaching its close, and that I desire to aid others who may chance to traverse the ground I have passed over, or who may be preparing to pass beyond the point I have reached.

To a naturalist of seventy years the greater part of life lies in the past, and in revising these papers I have necessarily had my thoughts directed to the memory of friends, teachers, guides, and companions in labour, who have passed away. I have therefore, as a slight token of loving and grateful remembrance dedicated these papers to the memory of men I have known and loved, and who, I feel, would sympathise with me in spirit, in the attempt, however feeble, to direct attention to the variety and majesty of those great works of the Creator which they themselves delighted to study.

Since the design of these papers excludes special details as to Canadian geology, or that of those old eastern countries to which I have given some attention, I must refer for them to other works, and shall append such reference of this kind as may be necessary. At the same time it will be observed that as my geological work has been concerned most largely with the oldest and newest rocks of the earth, and with the history of life rather than with rocks and minerals, there must necessarily be some preponderance in these directions, which might however, independently of personal considerations, be justified by the actual value of these lines of investigation, and by the

special interest attaching to them in the present state of scientific discovery.

Having thus defined my starting-point, I would now with all respect and deference ask the reader to accompany me from point to point, and to examine for himself the objects which may appear either near, or in the dim uncertain distance, in illustration of what the world is, and how it became what it is. Perhaps, in doing so, he may be able to perceive much more than I have been able to discover; and if so, I shall rejoice, even if such further insight should correct or counteract some of my own impressions. It is not given to any one age or set of men to comprehend all the mysteries of nature, or to arrive at a point where it can be said, there is no need of farther exploration. Even in the longest journey of the most adventurous traveller there is an end of discovery, and, in the study of nature, cape rises beyond cape and mountain behind mountain interminably. The finite cannot comprehend the infinite, the temporal the eternal. We need not, however, on that account be agnostics, for it is still true that, within the scope of our narrow powers and opportunities, the Supreme Intelligence reveals to us in nature His power and divinity; and it is this, and this alone, that gives attraction and dignity to natural science.

WORLD-MAKING.

DEDICATED TO THE MEMORY OF

ADAM SEDGWICK AND SIR RODERICK IMPEY MURCHISON,

WHOSE JOINT LABOURS CARRIED

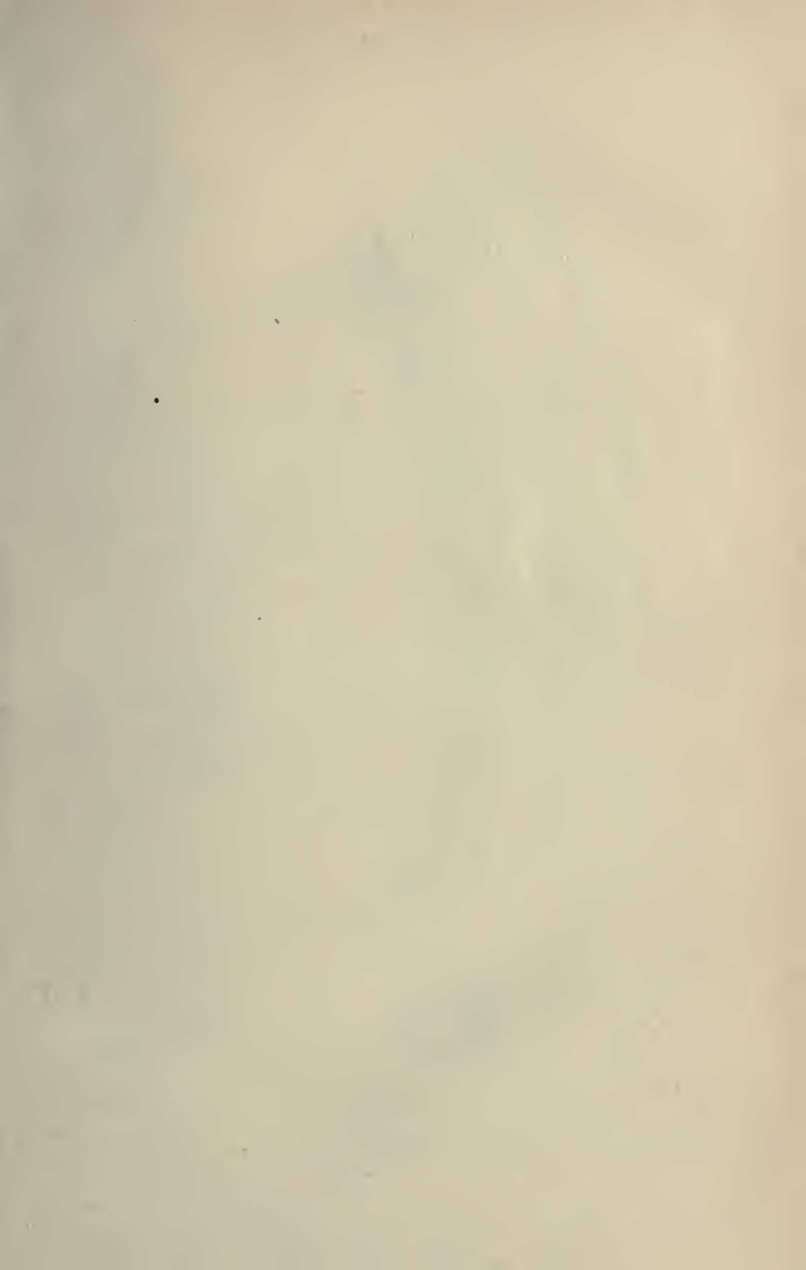
OUR KNOWLEDGE OF THE HISTORY OF THE EARTH

TWO STAGES FARTHER BACK,

AND WHOSE DIFFERENCES OF OPINION SERVED TO RENDER

MORE GLORIOUS THEIR VICTORIES.

Vision of a Nascent World—The Oldest Rocks—Development of Life—Formation of Continents—In what Sense Permanent—America as an Example



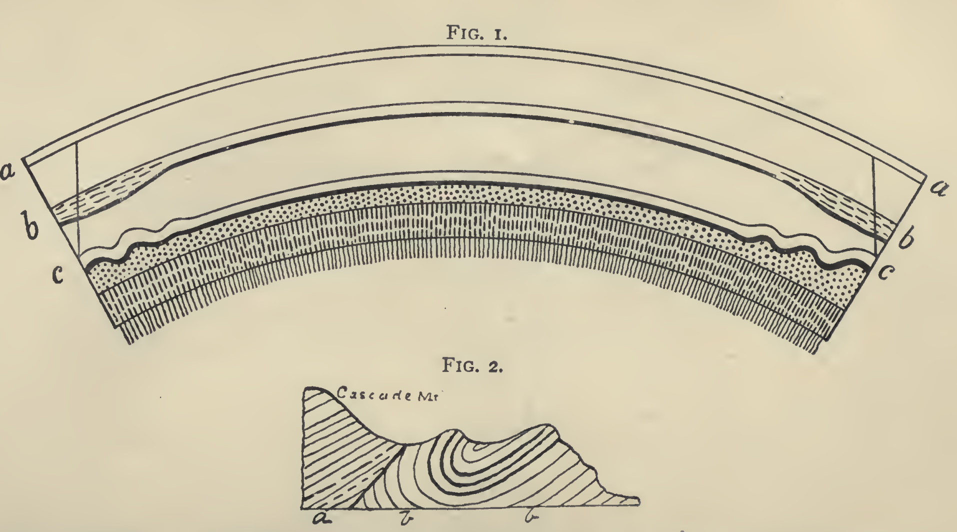


Fig. 1. Diagram illustrating Folding of the Crust of the Earth.—(*a*) Undisturbed crust. (*b*) Primary depression and deposition. (*c*) Mountain-making folds with their relations to an upper and lower magma. Fig. 2. Result of folding, faulting, and denudation, as seen at Cascade Mountain, Western Canada (after McConnell, p. 33).

CHAPTER II.

WORLD-MAKING.

GEOLOGICAL reading, especially when of a strictly uniformitarian character and in warm weather, sometimes becomes monotonous; and I confess to a feeling of drowsiness creeping over me when preparing material for a presidential address to the American Association for the Advancement of Science in August, 1883. In these circumstances I became aware of the presence of an unearthly visitor, who announced himself as of celestial birth, and intimated to me that being himself free from those restrictions of space and time which are so embarrassing to earthly students, he was prepared for the moment to share these advantages with me, and to introduce me to certain outlying parts of the universe, where I might learn something of its origin and early history. He took my hand, and instantly we were in the voids of space. Turning after a moment, he pointed to a small star and said, "That is the star you call the sun; here, you see, it is only about the third magnitude, and in a few seconds it will disappear." These few seconds, indeed, reduced the whole visible firmament to a mere nebulous haze like the Milky Way, and we seemed to be in blank space. But pausing for a moment I became aware that around us were multitudes of dark bodies, so black that they were, so to speak, negatively visible, even in the almost total darkness around. Some seemed large and massive, some a mere drift of minute particles, formless and without distinct limits. Some were swiftly moving, others

stationary, or merely revolving on their own axes. It was a "horror of great darkness," and I trembled with fear. "This," said my guide, "is what the old Hebrew seer called *tohu ve bohu*, 'formless and void,' the 'Tiamat' or abyss of the old Chaldeans, the 'chaos and old night' of the Greeks. Your mundane physicists have not seen it, but they speculate regarding it, and occupy themselves with questions as to whether it can be lightened and vivified by mere attractive force, or by collision of dark bodies impinging on each other with vast momentum. Their speculations are vain, and lead to nothing, because they have no data wherefrom to calculate the infinite and eternal Power who determined either the attraction or the motion, or who willed which portion of this chaos was to become cosmos, and which was to remain for ever dead and dark. Let us turn, however, to a more hopeful prospect." We sped away to another scene. Here were vast luminous bodies, such as we call nebulæ. Some were globular, others disc-like, others annular or like spiral wisps, and some were composed of several concentric shells or rings. All were in rapid rotation, and presented a glorious and brilliant spectacle. "This," said my guide, "is matter of the same kind with that we have just been considering; but it has been set in active motion. The fiat 'Let there be light!' has been issued to it. Nor is its motion in vain. Each of these nebulous masses is the material of a system of worlds, and they will produce systems of different forms in accordance with the various shapes and motions which you observe. Such bodies are well known to earthly astronomers. One of them, the great nebula of Andromeda, has been photographed, and is a vast system of luminous rings of vapour placed nearly edgewise to the earth, and hundreds of times greater than the whole solar system. But now let us annihilate time, and consider these gigantic bodies as they will be in the course of many millions of years." Instantaneously these vast nebulæ had concentrated

themselves into systems of suns and planets, but with this difference from ours, that the suns were very large and surrounded with a wide luminous haze, and each of the planets was self-luminous, like a little sun. In some the planets were dancing up and down in spiral lines. In others they were moving in one plane. In still others, in every variety of direction. Some had vast numbers of little planets and satellites. Others had a few of larger size. There were even some of these systems that had a pair of central suns of contrasting colours. The whole scene was so magnificent and beautiful that I thought I could never weary of gazing on it. "Here," said he, "we have the most beautiful condition of systems of worlds, when considered from a merely physical point of view: the perfection of solar and planetary luminousness, but which is destined to pass away in the interest of things more important, if less showy. This is the condition of the great star Sirius, which the old priest astronomers of the Nile Valley made so much of in their science and religion, and which they called Sothis. It is now known by your stargazers to be vastly larger than your sun, and fifty times more brilliant.[1] Let us select one of these systems somewhat similar to the solar system, and suppose that the luminous atmospheres of its nearer planets are beginning to wane in brilliancy. Here is one of them, through whose halo of light we can see the body of the planet. What do you now perceive?" The planet referred to was somewhat larger in appearance than our earth, and, approaching near to it, I could see that it had a cloud-bearing firmament, and that it seemed to have continents and oceans, though disposed in more regular forms than on our own planet, and with a smaller proportion of land. Looking at it more closely, I searched in vain for

[1] In evidence of these and other statements I may refer to Huggins' recent address as President of the British Association, and to the "Story of the Heavens," etc., by Sir Robert Ball.

any sign of animal life, but I saw a vast profusion of what might be plants, but not like those of this world.[1] These were trees of monstrous stature, and their leaves, which were of great size and shaped like fronds of seaweeds, were not usually green, but variegated with red, crimson and orange. The surface of the land looked like beds of gigantic specimens of *Colias* and similar variegated-leaved plants, the whole presenting a most gorgeous yet grotesque spectacle. "This," said my guide, "is the primitive vegetation which clothes each of the planets in its youthful state. The earth was once so clothed, in the time when vegetable life alone existed, and there were no animals to prey upon it, and when the earth was, like the world you now look upon, a paradise of plants; for all things in nature are at first in their best estate. This vegetation is known to you on the earth only by the Carbon and Graphite buried in your oldest rocks. It still lingers on your neighbour Mars,[2] which has, however, almost passed beyond this stage, and we are looking forward before long to see a still more gigantic though paler development of it in altogether novel shapes on the great continents that are being formed on the surface of Jupiter. But look again." And time being again annihilated, I saw the same world, now destitute of any luminous envelope, with a few dark clouds in its atmosphere, and presenting just the same appearance which I would suppose our earth to present to an astronomer viewing it with a powerful telescope from the moon. "Here we are at home again," said my guide; "good-bye." I found myself nodding over my table, and that my pen had just dropped from my hand, making a large blot on my paper. My dream, however,

[1] We shall see farther on that there is reason to believe that the primitive land vegetation was more different from that of the Devonian and Carboniferous than it is from that of the present day.

[2] Mars is probably a stage behind the earth in its development, and the ruddy hue of its continents would seem to be due to some organic covering.

gave me a hint as to a subject, and I determined to devote my address to a consideration of questions which geology has not solved, or has only imperfectly and hypothetically discussed.

Such unsolved or partially solved questions must necessarily exist in a science which covers the whole history of the earth in time. At the beginning it allies itself with astronomy and physics and celestial chemistry. At the end it runs into human history, and is mixed up with archæology and anthropology. Throughout its whole course it has to deal with questions of meteorology, geography and biology. In short, there is no department of physical or biological science, with which this many-sided study is not allied, or at least on which the geologist may not presume to trespass. When, therefore, it is proposed to discuss in the present chapter some of the unsolved problems and disputed questions of this universal science, the reader need not be surprised if it should be somewhat discursive.

Perhaps we may begin at the utmost limits of the subject by remarking that in matters of natural and physical science we are met at the outset with the scarcely solved question as to our own place in the nature which we study, and the bearing of this on the difficulties we encounter. The organism of man is decidedly a part of nature. We place ourselves, in this aspect, in the sub-kingdom vertebrata and class mammalia, and recognise the fact that man is the terminal link in a chain of being, extending throughout geological time. But the organism is not all that belongs to man, and when we regard him as a scientific inquirer, we raise a new question. If the human mind is a part of nature, then it is subject to natural law, and nature includes mind as well as matter. Indeed, without being absolute idealists we may hold that mind is more potent than matter, and nearer to the real essence of things. Our science is in any case necessarily dualistic, being the product

of the reaction of mind on nature, and must be largely subjective and anthropomorphic. Hence, no doubt, arises much of the controversy of science, and much of the unsolved difficulty. We recognise this when we divide science into that which is experimental, or depends on apparatus, and that which is observational and classificatory—distinctions these which relate not so much to the objects of science as to our methods of pursuing them. This view also opens up to us the thought that the domain of science is practically boundless, for who can set limits to the action of mind on the universe, or of the universe on mind. It follows that science, as it exists at any one time, must be limited on all sides by unsolved mysteries; and it will not serve any good purpose to meet these with clever guesses. If we so treat the enigmas of the sphinx nature, we shall surely be devoured. Nor, on the other hand, must we collapse into absolute despair, and resign ourselves to the confession of inevitable ignorance. It becomes us rather boldly to confront the unsolved questions of nature, and to wrestle with their difficulties till we master such as we can, and cheerfully leave those we cannot overcome to be grappled with by our successors.

Fortunately, as a geologist, I do not need to invite attention to those transcendental questions which relate to the ultimate constitution of matter, the nature of the ethereal medium filling space, the absolute difference or identity of chemical elements, the cause of gravitation, the conservation and dissipation of energy, the nature of life, or the primary origin of bioplasmic matter. I may take the much more humble *rôle* of an inquirer into the unsolved or partially solved problems which meet us in considering that short and imperfect record which geology studies in the rocky layers of the earth's crust, and which leads no farther back than to the time when a solid rind had already formed on the earth, and was already covered with an ocean. This record of geology covers but a small

part of the history of the earth and of the system to which it belongs, nor does it enter at all into the more recondite problems involved; still it forms, I believe, some necessary preparation at least to the comprehension of these. If we are to go farther back, we must accept the guidance of physicists rather than of geologists, and I must say that in this physical cosmology both geologists and general readers are likely to find themselves perplexed with the vagaries in which the most sober mathematicians may indulge. We are told that the original condition of the solar system was that of a vaporous and nebulous cloud intensely heated and whirling rapidly round, that it probably came into this condition by the impact of two dark solid bodies striking each other so violently, that they became intensely heated and resolved into the smallest possible fragments. Lord Kelvin attributes this impact to their being attracted together by gravitative force. Croll[1] argues that in addition to gravitation these bodies must have had a proper motion of great velocity, which Lord Kelvin thinks "enormously" improbable, as it would require the solid bodies to be shot against each other with a marvellously true aim, and this not in the case of the sun only, but of all the stars. It is rather more improbable than it would be to affirm that in the artillery practice of two opposing armies, cannon balls have thousands of times struck and shattered each other midway between the hostile batteries. The question, we are told, is one of great moment to geologists, since on the one hypothesis the duration of our system has amounted to only about twenty millions of years; on the other, it may have lasted ten times that number.[2] In any case it seems a strange way of making systems of worlds, that they should result from the chance collision of multitudes of solid bodies

[1] "Stellar Evolution."

[2] Other facts favour the shorter time (Clarence King, *Am. Jl. of Science*, vol. xlv., 3rd series).

rushing hither and thither in space, and it is almost equally strange to imagine an intelligent Creator banging these bodies about like billiard balls in order to make worlds. Still, in that case we might imagine them not to be altogether aimless. The question only becomes more complicated when with Grove and Lockyer we try to reach back to an antecedent condition, when there are neither solid masses nor nebulæ, but only an inconceivably tenuous and universally diffused medium made up of an embryonic matter, which has not yet even resolved itself into chemical elements. How this could establish any motion within itself tending to aggregation in masses, is quite inconceivable. To plodding geologists laboriously collecting facts and framing conclusions therefrom, such flights of the mathematical mind seem like the wildest fantasies of dreams. We are glad to turn from them to examine those oldest rocks, which are to us the foundation stones of the earth's crust.

What do we know of the oldest and most primitive rocks? At this moment the question may be answered in many and discordant ways; yet the leading elements of the answer may be given very simply. The oldest rock formation known to geologists is the Lower Laurentian, the Fundamental Gneiss, the Lewisian formation of Scotland, the Ottawa gneiss of Canada, the lowest Archæan crystalline rocks. This formation, of enormous thickness, corresponds to what the older geologists called the fundamental granite, a name not to be scouted, for gneiss is only a stratified or laminated granite. Perhaps the main fact in relation to this old rock is that it is a gneiss; that is, a rock at once bedded and crystalline, and having for its dominant ingredient the mineral orthoclase, a compound of silica, alumina and potash, in which are imbedded, as in a paste, grains and crystals of quartz and hornblende. We know very well from its texture and composition that it cannot be a product of mere heat, and being a bedded rock

we infer that it was laid down layer by layer in the manner of aqueous deposits. On the other hand, its chemical composition is quite different from that of the muds, sands and gravels usually deposited from water. Their special characters are caused by the fact that they have resulted from the slow decay of rocks like these gneisses, under the operation of carbon dioxide and water, whereby the alkaline matter and the more soluble part of the silica have been washed away, leaving a residue mainly silicious and aluminous. Such more modern rocks tell of dry land subjected to atmospheric decay and rain-wash. If they have any direct relation to the old gneisses, they are their grandchildren, not their parents. On the contrary, the oldest gneisses show no pebbles or sand or limestone—nothing to indicate that there was then any land undergoing atmospheric waste, or shores with sand and gravel. For all that we know to the contrary, these old gneisses may have been deposited in a shoreless sea, holding in solution or suspension merely what it could derive from a submerged crust recently cooled from a state of fusion, still thin, and exuding here and there through its fissures heated waters and volcanic products. This, it may be observed here, is just what we have a right to expect, if the earth was once a heated or fluid mass, and if our oldest Laurentian rocks consist of the first beds or layers deposited upon it, perhaps by a heated ocean. It has been well said that "the secret of the earth's hot youth has been well kept." But with the help of physical science we can guess at an originally heat-liquefied ball with denser matter at its centre, lighter and oxidised matter at its surface. We can imagine a scum or crust forming at the surface; and from what we know of the earth's interior, nothing is more likely to have constituted that slaggy

[1] Carbon dioxide, the great agent in the decay of silicious rocks, must then have constituted a very much larger part of the atmosphere than at present.

crust than the material of our old gneisses. As to its bedded character, this may have arisen in part from the addition of cooling layers below, in part from the action of heated water above, and in part from pressure or tension; while, wherever it cracked or became broken, its interstices would be injected with molten matter from beneath. All this may be conjecture, but it is based on known facts, and is the only probable conjecture. If correct, it would account for the fact that the gneissic rocks are the lowest and oldest that we reach in every part of the earth.

In short, the fundamental gneiss of the Lower Laurentian may have been the first rock ever formed; and in any case it is a rock formed under conditions which have not since recurred, except locally. It constitutes the first and best example of those chemico-physical, aqueous or aqueo-igneous rocks, so characteristic of the earliest period of the earth's history. Viewed in this way the Lower Laurentian gneiss is probably the oldest kind of rock we shall ever know—the limit to our backward progress, beyond which there remains nothing to the geologist except physical hypotheses respecting a cooling incandescent globe. For the chemical conditions of these primitive rocks, and what is known as to their probable origin, I may refer to the writings of my friends, the late Dr. Sterry Hunt and Dr. J. G. Bonney, to whom we owe so much of what is known of the older crystalline rocks[1] as well as of their literature, and the questions which they raise. My purpose here is to sketch the remarkable difference which we meet as we ascend into the Middle and Upper Laurentian.

In the next succeeding formation, the middle part of the Laurentian of Logan, the Grenville series of Canada, we meet with a great and significant change. It is true we have still a predominance of gneisses which may have been formed in the

[1] Hunt, "Essays on Chemical Geology"; Bonney, "Addresses to British Association and Geological Society of London."

same manner with those below them; but we find these now associated with great beds of limestone and dolomite, which must have been formed by the separation of calcium and magnesium carbonates from the sea water, either by chemical precipitation or by the agency of living beings. We have also quartzite, quartzose gneisses, and even pebble beds, which inform us of sandbanks and shores. Nay, more, we have beds containing graphite which must be the residue of plants, and iron ores which tell of the deoxidation of iron oxide by organic matters. In short, here we have evidence of new factors in world-building, of land and ocean, of atmospheric decay of rocks, of deoxidizing processes carried on by vegetable life on the land and in the waters, of limestone-building in the sea. To afford material for such rocks, the old Ottawa gneiss must have been lifted up into continents and mountain masses by bendings and foldings of the original crust. Under the slow but sure action of the carbon dioxide dissolved in rainwater, its felspar had crumbled down in the course of ages. Its potash, soda, lime, magnesia, and part of its silica had been washed into the sea, there to enter into new combinations and to form new deposits. The crumbling residue of fine clay and sand had been also washed down into the borders of the ocean, and had been there deposited in beds. Thus the earth had entered into a new phase, which continues onward through the geological ages; and I place in the reader's hands one key for unlocking the mystery of the world in affirming that this great change took place, this new era was inaugurated in the midst of the Laurentian period, the oldest of our great divisions of the earth's geological history.[1]

[1] I follow the original arrangement of Logan, who first defined this succession in the extensive and excellent exposures of these rocks in Canada. Elsewhere the subject has often been confused and mixed with local details. The same facts, though sometimes under different names, are recorded by the geologists of Scandinavia, Britain, and the United States,

Was not this a fit period for the first appearance of life? should we not expect it to appear, independently of the evidence of the fact, so soon at least as the temperature of the ocean falls sufficiently low to permit its existence?[1] I do not propose to enter here into that evidence. This we shall have occasion to consider in the sequel. I would merely say here that we should bear in mind that in this latter half of the Lower Laurentian, or if we so choose to style it, Middle Laurentian period, we have the conditions required for life in the sea and on the land; and since in other periods we know that life was always present when its conditions were present, it is not unreasonable to look for the earliest traces of life in this formation, in which we find, for the first time, the completion of those physical arrangements which make life, in such forms of it as exist in the sea, possible.

This is also a proper place to say something of the disputed doctrine of what is termed metamorphism, or the chemical and molecular changes which old rocks have undergone.

The Laurentian rocks are undoubtedly greatly changed from their original state, more especially in the matters of crystallization and the formation of disseminated minerals, by the action of heat and heated water. Sandstones have thus passed into quartzites, clays into slates and schists, limestones into marbles. So far, metamorphism is not a doubtful question; but when theories of metamorphism go so far as to suppose an actual change of one element for another, they go beyond the bounds of chemical credibility; yet such theories of metamorphism are often boldly advanced and made the basis of important conclusions. Dr. Hunt has happily given the name "metasomatosis" to this imaginary and improbable kind of

and the acceptance of the conclusions of Nicol and Lapworth has served to bring even the rocks of the Highlands of Scotland more into line with those of Canada.

[1] Dana states this at 180° F. for plants and 120° for animals.

metamorphism. I would have it to be understood that, in speaking of the metamorphism of the older crystalline rocks, it is not to this metasomatosis that I refer, and that I hold that rocks which have been produced out of the materials decomposed by atmospheric erosion can never by any process of metamorphism be restored to the precise condition of the Laurentian rocks. Thus, there is in the older formations a genealogy of rocks, which, in the absence of fossils, may be used with some confidence, but which does not apply to the more modern deposits, and which gives a validity to the use of mineral character in classifying older rocks which does not hold for later formations. Still, nothing in geology absolutely perishes, or is altogether discontinued ; and it is probable that, down to the present day, the causes which produced the old Laurentian gneiss may still operate in limited localities. Then, however, they were general, not exceptional. It is further to be observed that the term gneiss is sometimes of wide and even loose application. Beside the typical orthoclase and hornblendic gneiss of the Laurentian, there are micaceous, quartzose, garnetiferous and many other kinds of gneiss ; and even gneissose rocks, which hold labradorite or anorthite instead of orthoclase, are sometimes, though not accurately, included in the term.

The Grenville series, or Middle Laurentian, is succeeded by what Logan in Canada called the Upper Laurentian, and which other geologists have called the Norite or Norian series. Here we still have our old friends the gneisses, but somewhat peculiar in type, and associated with them are great beds and masses, rich in lime-felspar, the so-called labradorite and anorthite rocks. The precise origin of these is uncertain, but this much seems clear, namely, that they originated in circumstances in which the great limestones deposited in the Lower or Middle Laurentian were beginning to be employed in the manufacture, probably by aqueo-igneous agencies, of lime-felspars. This proves

the Norian rocks to be younger than the Lower Laurentian, and that, as Logan supposed, considerable earth movements had occurred between the two, implying lapse of time, while it is also evident that the folding and crumpling of the Lower Laurentian had led to great outbursts of igneous matter from below the crust, or from its under part.

Next to the Laurentian, but probably after an interval, the rocks of which are yet scarcely known, we have the Huronian of Logan, a series much less crystalline and more fragmentary, and affording more evidence of land elevation and atmospheric and aqueous erosion than those preceding it. It has extensive beds of volcanic rock, great conglomerates, some of them made up of rounded fragments of Laurentian rocks, and others of quartz pebbles, which must have been the remains of rocks subjected to very perfect decay. The pure quartz-rocks tell the same tale, while slates and limestones speak also of chemical separation of the materials of older rocks. The Huronian evidently tells of previous movements in the Laurentian, and changes which allowed the Huronian to be deposited along its shores and on the edges of its beds. Yet the Huronian itself is older than the Palæozoic series, and affected by powerful earth movements at an earlier date. Life existed in the waters in Huronian times. We have spicules of sponges in the limestone, and organic markings on the slaty beds; but they are few, and their nature is uncertain.

Succeeding the Huronian, and made up of its *débris* and that of the Laurentian, we have the great Cambrian series, that in which we first find undoubted evidence of abundant marine life, and which thus forms the first chapter in the great Palæozoic book of the early history of the world. Here let it be observed we have at least two wide gaps in our history, marked by the crumpling up, first, of the Laurentian, and then of the Huronian beds.

After what has been said, the reader will perhaps not be

astonished that fierce geological battles have raged over the old crystalline rocks. By some geologists they are almost entirely explained away, or referred to igneous action, or to the alteration of ordinary sediments. Under the treatment of another school they grow to great series of Pre-Cambrian rocks, constituting vast systems of formations, distinguishable from each other chiefly by differences of mineral character. Facts and fossils are daily being discovered, by which these disputes will ultimately be settled.

After the solitary appearance of Eozoon in the Laurentian, and of a few uncertain forms in the Huronian, we find ourselves, in the Cambrian, in the presence of a nearly complete invertebrate fauna of protozoa, polyps, echinoderms, mollusks and crustacea, and this not confined to one locality merely, but apparently extended simultaneously throughout the ocean, over the whole world. This sudden incoming of animal life, along with the subsequent introduction of successive groups of invertebrates, and finally of vertebrate animals, furnishes one of the greatest unsolved problems of geology, which geologists were wont to settle by the supposition of successive creations. In the sequel I shall endeavour to set forth the facts as to this succession, and the general principles involved in it, and to show the insufficiency of certain theories of evolution suggested by biologists to give any substantial aid to the geologist in these questions. At present I propose merely to notice some of the general principles which should guide us in studying the development of life in geological time, and the causes which have baffled so many attempts to throw light on this obscure portion of our unsolved problems.

It has been urged on the side ot rational evolution—and there are both rational and irrational forms of this many-sided doctrine—that this hypothesis does not profess to give an explanation of the absolute origin of life on our planet, or even of the original organization of a single cell, or of a simple mass

of protoplasm, living or dead. All experimental attempts to produce by synthesis the complex albuminous substances, or to obtain the living from the non-living, have so far been fruitless, and indeed we cannot imagine any process by which such changes could be effected. That they have been effected we know, but the process employed by their maker is still as mysterious to us as it probably was to him who wrote the words :—" And God said, Let the waters swarm with swarmers." How vast is the gap in our knowledge and our practical power implied in this admission, which must, however, be made by every mind not absolutely blinded by a superstitious belief in those forms of words which too often pass current as philosophy.

But if we are content to start with a number of organisms ready made—a somewhat humiliating start, however—we still have to ask—How do these vary so as to give new species? It is a singular illusion, and especially in the case of men who profess to be believers in natural law, that variation may be boundless, aimless and fortuitous, and that it is by spontaneous selection from varieties thus produced that development arises. But surely the supposition of mere chance and magic is unworthy of science. Varieties must have causes, and their causes and their effects must be regulated by some law or laws. Now it is easy to see that they cannot be caused by a mere innate tendency in the organism itself. Every organism is so nicely equilibrated that it has no such spontaneous tendency, except within the limits set by its growth and the law of its periodical changes. There may, however, be equilibrium more or less stable. I believe all attempts hitherto made have failed to account for the fixity of certain, nay, of very many, types throughout geological time, but the mere consideration that one may be in a more stable state of equilibrium than another, so far explains it. A rocking stone has no more spontaneous tendency to move than an ordinary boulder, but

it may be made to move with a touch. So it probably is with organisms. But if so, then the causes of variation are external, as in many cases we actually know them to be, and they must depend on instability with change in surroundings, and this so arranged as not to be too extreme in amount, and to operate in some determinate direction. Observe how remarkable the unity of the adjustments involved in such a supposition!—how superior they must be to our rude and always more or less unsuccessful attempts to produce and carry forward varieties and races in definite directions! This cannot be chance. If it exists, it must depend on plans deeply laid in the nature of things, else it would be most monstrous magic and causeless miracle. Still more certain is this conclusion when we consider the vast and orderly succession made known to us by geology, and which must have been regulated by fixed laws, only a few of which are as yet known to us.

Beyond these general considerations we have others of a more special character, based on palæontological facts, which show how imperfect are our attempts as yet to reach the true causes of the introduction of genera and species.

One is the remarkable fixity of the leading types of living beings in geological time. If, instead of framing, like Haeckel, fanciful phylogenies, we take the trouble, with Barrande and Gaudry, to trace the forms of life through the period of their existence, each along its own line, we shall be greatly struck with this, and especially with the continuous existence of many low types of life through vicissitudes of physical conditions of the most stupendous character, and over a lapse of time scarcely conceivable. What is still more remarkable is that this holds in groups which, within certain limits, are perhaps the most variable of all. In the present world no creatures are individually more variable than the protozoa; as, for example, the foraminifera and the sponges. Yet these groups are fundamentally the same, from the beginning of the Palæo-

zoic until now, and modern species seem scarcely at all to differ from specimens procured from rocks at least half-way back to the beginning of our geological record. If we suppose that the present sponges and foraminifera are the descendants of those of the Silurian period, we can affirm that in all that vast lapse of time they have, on the whole, made little greater change than that which may be observed in variable forms at present. The same remark applies to other low animal forms. In types somewhat higher and less variable, this is almost equally noteworthy. The pattern of the venation of the wings of cockroaches, and the structure and form of land snails, gally-worms and decapod crustaceans were all settled in the Carboniferous age, in a way that still remains. So were the foliage and the fructification of club-mosses and ferns. If, at any time, members of these groups branched off, so as to lay the foundation of new species, this must have been a very rare and exceptional occurrence, and one demanding even some suspension of the ordinary laws of nature.

We may perhaps be content on this question to say with Gaudry,[1] that it is not yet possible to "pierce the mystery that surrounds the development of the great classes of animals," or with Prof. Williamson,[2] that in reference to fossil plants "the time has not yet arrived for the appointment of a botanical King-at-arms and Constructor of pedigrees." We shall, however, find that by abandoning mere hypothetical causes and carefully noting the order of the development and the causes in operation, so far as known, we may reach to ideas as to cause and mode, and the laws of succession, even if unable to penetrate the mystery of origins.

Another caution which a palæontologist has occasion to give with regard to theories of life, has reference to the tendency of biologists to infer that animals and plants were introduced

[1] "Enchainements du Monde Animal," Paris, 1883.

[2] Address before Royal Institution, Feb., 1883.

under embryonic forms, and at first in few and imperfect species. Facts do not substantiate this. The first appearance of leading types of life is rarely embryonic, or of the nature of immature individuals. On the contrary, they often appear in highly perfect and specialized forms, often, however, of composite type and expressing characters afterwards so separated as to belong to higher groups. The trilobites of the Cambrian are some of them of few segments, and so far embryonic, but the greater part are many-segmented and very complex. The batrachians of the Carboniferous present many characters higher than those of their modern successors and now appropriated to the true reptiles. The reptiles of the Permian and Trias usurped some of the prerogatives of the mammals. The ferns, lycopods and equisetums of the Devonian and Carboniferous were, in fructification, not inferior to their modern representatives, and in the structure of their stems far superior. The shell-bearing cephalopods of the Palæozoic would seem to have possessed structures now special to a higher group, that of the cuttle-fishes. The bald and contemptuous negation of these facts by Haeckel and other biologists does not tend to give geologists much confidence in their dicta.

Again, we are now prepared to say that the struggle for existence, however plausible as a theory, when put before us in connection with the productiveness of animals and the few survivors of their multitudinous progeny, has not been the determining cause of the introduction of new species. The periods of rapid introduction of new forms of marine life were not periods of struggle, but of expansion—those periods in which the submergence of continents afforded new and large space for their extension and comfortable subsistence. In like manner, it was continental emergence that afforded the opportunity for the introduction of land animals and plants. Further, in connection with this, it is now an established conclusion that the great aggressive faunas and floras of the continents

have originated in the north, some of them within the arctic circle, and this in periods of exceptional warmth, when the perpetual summer sunshine of the arctic regions coëxisted with a warm temperature. The testimony of the rocks thus is that not struggle but expansion furnished the requisite conditions for new forms of life, and that the periods of struggle were characterized by depauperation and extinction.

But we are sometimes told that organisms are merely mechanical, and that the discussions respecting their origin have no significance any more than if they related to rocks or crystals, because they relate merely to the organism considered as a machine, and not to that which may be supposed to be more important, namely, the great determining power of mind and will. That this is a mere evasion by which we really gain nothing, will appear from a characteristic extract of an article by an eminent biologist in the new edition of the Encyclopedia Britannica, a publication which, I am sorry to say, instead of its proper *rôle* as a repertory of facts, has admitted partisan papers, stating extreme and unproved speculations as if they were conclusions of science. The statement referred to is as follows :—" A mass of living protoplasm is simply a molecular machine of great complexity, the total results of the working of which, or its vital phenomena, depend on the one hand on its construction, and on the other, on the energy supplied to it; and to speak of vitality as anything but the name for a series of operations is as if one should talk of the horologity of a clock." It would, I think, scarcely be possible to put into the same number of words a greater amount of unscientific assumption and unproved statement than in this sentence. Is "living protoplasm" different in any way from dead protoplasm, and if so, what causes the difference? What is a "machine"? Can we conceive of a self-produced or uncaused machine, or one not intended to work out some definite results? The results of the machine in question are said to be "vital phenomena";

certainly most wonderful results, and greater than those of any machine man has yet been able to construct. But why "vital"? If there is no such thing as life, surely they are merely physical results. Can mechanical causes produce other than physical effects? To Aristotle life was "the cause of form in organisms." Is not this quite as likely to be true as the converse proposition? If the vital phenomena depend on the "construction" of the machine, and the "energy supplied to it," whence this construction and whence this energy? The illustration of the clock does not help us to answer this question. The construction of the clock depends on its maker, and its energy is derived from the hand that winds it up. If we can think of a clock which no one has made, and which no one winds, a clock constructed by chance, set in harmony with the universe by chance, wound up periodically by chance, we shall then have an idea parallel to that of an organism living, yet without any vital energy or creative law; but in such a case we should certainly have to assume some antecedent cause, whether we call it "horologity" or by some other name. Perhaps the term evolution would serve as well as any other, were it not that common sense teaches that nothing can be spontaneously evolved out of that in which it did not previously exist.

There is one other unsolved problem in the study of life by the geologist to which it is still necessary to advert. This is the inability of palæontology to fill up the gaps in the chain of being. In this respect we are constantly taunted with the imperfection of the record, a matter so important that it merits a separate treatment; but facts show that this is much more complete than is generally supposed. Over long periods of time and many lines of being we have a nearly continuous chain, and if this does not show the tendency desired, the fault is as likely to be in the theory as in the record. On the other hand, the abrupt and simultaneous appearance of new types in many specific and generic forms and over wide and

separate areas at one and the same time, is too often repeated to be accidental. Hence palæontologists, in endeavouring to establish evolution, have been obliged to assume periods of exceptional activity in the introduction of species, alternating with others of stagnation, a doctrine differing very little from that of special creation, as held by the older geologists.

The attempt has lately been made to account for these breaks by the assumption that the geological record relates only to periods of submergence, and gives no information as to those of elevation. This is manifestly untrue. In so far as marine life is concerned, the periods of submergence are those in which new forms abound for very obvious reasons, already hinted; but the periods of new forms of land and fresh-water life are those of elevation, and these have their own records and monuments, often very rich and ample, as, for example, the swamps of the Carboniferous, the transition from the great Cretaceous subsidence, when so much of the land of the Northern Hemisphere was submerged, to the new continents of the Tertiary, the Tertiary lake-basins of Western America, the Terraces and raised beaches of the Pleistocene. Had I time to refer in detail to the breaks in the continuity of life which cannot be explained by the imperfection of the record, I could show at least that nature in this case does advance *per saltum*—by leaps, rather than by a slow continuous process. Many able reasoners, as Le Conte, in America, and Mivart and Collard in England, hold this view.

Here, as elsewhere, a vast amount of steady conscientious work is required to enable us to solve the problems of the history of life. But if so, the more the hope for the patient student and investigator. I know nothing more chilling to research, or unfavourable to progress, than the promulgation of a dogmatic decision that there is nothing to be learned but a merely fortuitous and uncaused succession, amenable to no law. and only to be covered, in order to hide its shapeless and

uncertain proportions, by the mantle of bold and gratuitous hypothesis.

So soon as we find evidence of continents and oceans we raise the question, Have these continents existed from the first in their present position and form, or have the land and water changed places in the course of geological time? This question also deserves a separate and more detailed consideration. In reality both statements are true in a certain limited sense. On the one hand, any geological map whatever suffices to show that the general outline of the existing land began to be formed in the first and oldest crumplings of the crust. On the other hand, the greater part of the surface of the land consists of marine sediments which must have been deposited when the continents were in great part submerged, and whose materials must have been derived from land that has perished in the process, while all the continental surfaces, except, perhaps, some high peaks and ridges, have been many times submerged. Both of these apparently contradictory statements are true; and without assuming both, it is impossible to explain the existing contours and reliefs of the surface.

In exceptional cases even portions of deep sea have been elevated, as in the case of the Polycistine deposits in the West Indies; but these exceptions are as yet scarcely sufficient to prove the rule.

In the case of North America, the form of the old nucleus of Laurentian rock in the north already marks out that of the finished continent, and the successive later formations have been laid upon the edges of this, like the successive loads of earth dumped over an embankment. But in order to give the great thickness of the Palæozoic sediments, the land must have been again and again submerged, and for long periods of time. Thus, in one sense, the continents have been fixed; in another, they have been constantly fluctuating. Hall and Dana have well illustrated these points in so far as eastern North America

is concerned. Prof. Hull of the Geological Survey of Ireland has had the boldness to reduce the fluctuations of land and water, as evidenced in the British Islands, to the form of a series of maps intended to show the physical geography of each successive period. The attempt is probably premature, and has been met with much adverse criticism; but there can be no doubt that it has an element of truth. When we attempt to calculate what could have been supplied from the old Eozoic nucleus by decay and aqueous erosion, and when we take into account the greater local thickness of sediments towards the present sea-basins, we can scarcely avoid the conclusion that extensive areas once occupied by high land are now under the sea. But to ascertain the precise areas and position of these perished lands may now be impossible.

In point of fact we are obliged to believe in the contemporaneous existence in all geological periods, except perhaps the very oldest, of three sorts of areas on the surface of the earth: (1) Oceanic areas of deep sea, which must always have occupied the bed of the present ocean, or parts of it; (2) Continental plateaus sometimes existing as low flats, or as higher table-lands, and sometimes submerged; (3) Areas of plication or folding, more especially along the borders of the oceans, forming elevated lands rarely submerged and constantly affording the material of sedimentary accumulations. We shall find, however, that these have changed places in a remarkable manner, though always in such a way that neither the life of the land nor of the waters was wholly extinguished in the process.

Every geologist knows the contention which has been occasioned by the attempts to correlate the earlier Palæozoic deposits of the Atlantic margin of North America with those forming at the same time on the interior plateau, and with those of intervening lines of plication and igneous disturbance. Stratigraphy, lithology and fossils are all more or less at fault in dealing with these questions, and while the general nature

of the problem is understood by many geologists, its solution in particular cases is still a source of apparently endless debate.

The causes and mode of operation of the great movements of the earth's crust which have produced mountains, plains and table-lands, are still involved in some mystery. One patent cause is the unequal settling of the crust towards the centre; but it is not so generally understood as it should be, that the greater settlement of the ocean-bed has necessitated its pressure against the sides of the continents in the same manner that a huge ice-floe crushes a ship or a pier. The geological map of North America shows this at a glance, and impresses us with the fact that large portions of the earth's crust have not only been folded but bodily pushed back for great distances. On looking at the extreme north, we see that the great Laurentian mass of central Newfoundland has acted as a projecting pier to the space immediately west of it, and has caused the gulf of St. Lawrence to remain an undisturbed area since Palæozoic times. Immediately to the south of this, Nova Scotia and New Brunswick are folded back. Still farther south, as Guyot has shown, the old sediments have been crushed in sharp folds against the Adirondack mass, which has sheltered the table-land of the Catskills and of the great lakes. South of this again the rocks of Pennsylvania and Maryland have been driven back in a great curve to the west. Movements of this kind on the Pacific coast of America have been still more stupendous, as well as more recent. Dr. G. M. Dawson[1] thus refers to the crushing action of the Pacific bed on the rocks of British Columbia, and this especially at two periods, the close of the Triassic and the close of the Cretaceous: "The successive foldings and crushings which the Cordillera region has suffered have resulted in an actual change of position of the rocks now composing its western margin.

[1] Trans. Royal Society of Canada, 1890.

This change may have amounted since the beginning of Mesozoic time to one-third of its whole present width, which would place the line of the coast ranges about two degrees of longitude farther west." Here we have evidence that a tract of country 400 miles wide and consisting largely of mountain ranges and table-lands, has been crushed bodily back over two degrees of longitude; and this applies not to British Columbia merely, but to the whole west coast from Alaska to Chili. Yet we know that any contraction of the earth's nucleus can crumple up only a very thin superficial crust, which in this case must have slid over the pasty mass below.[1] Let it be observed, however, that the whole lateral pressure of vast areas has been condensed into very narrow lines. Nothing, I think, can more forcibly show the enormous pressure to which the edges of the continents have been exposed, and at the same time the great sinking of the hard and resisting ocean-beds. Complex and difficult to calculate though these movements of plication are, they are more intelligible than the apparently regular pulsations of the flat continental areas, whereby they have alternately been below and above the waters, and which must have depended on somewhat regularly recurring causes, connected either with the secular cooling of the earth or with the gradual retardation of its rotation, or with both. There is, however, good reason to believe that the successive subsidences alternated with the movements of plication, and depended on upward bendings of the ocean floor, and also on the gradual slackening of the rotation of the earth. Throughout these changes, each successive elevation exposed the rocks for long ages to the decomposing influence of the atmosphere. Each submergence swept away and deposited as

[1] This view is quite consistent with the practical solidity of the earth, and with the action of local expansion by heat, of settlement of areas overloaded with sediment, and of downward sliding of beds. This we shall see in the sequel.

sediment the material accumulated by decay. Every change of elevation was accompanied with changes of climate, and with modifications of the habitats of animals and plants. Were it possible to restore accurately the physical geography of the earth in all these respects, for each geological period, the data for the solution of many difficult questions would be furnished.

We have wandered through space and time sufficiently for one chapter, and some of the same topics must come up later in other connections. Let us sum up in a word. In human history we are dealing with the short lives and limited plans of man. In the making of worlds we are conversant with the plans of a Creator with whom one day is as a thousand years, and a thousand years as one day. We must not measure such things by our microscopic scale of time. Nor should we fail to see that vast though the ages of the earth are, they are parts of a continuous plan, and of a plan probably reaching in space and time immeasurably beyond our earth. When we trace the long history from an incandescent fire-mist to a finished earth, and vast ages occupied by the dynasties of plant and animal life, we see not merely a mighty maze, an almost endless procession of changes, but that all of these were related to one another by a chain of causes and effects leading onward to greater variety and complexity, while retaining throughout the traces of the means employed. The old rocks and the ancient lines of folding and the perished forms of life are not merely a scaffolding set up to be thrown down, but the foundation stones of a great and symmetrical structure. Is it yet completed? Who can tell? The earth may still be young, and infinite ages of a better history may lie before it.

REFERENCES[1]: Presidential Address to the American Association for the Advancement of Science, meeting at Minneapolis, 1883. "The Story of the Earth and Man." Ninth edition, London, 1887.

[1] The references in this and succeeding chapters are exclusively to papers and works by the author, on which the several chapters are based.



THE IMPERFECTION OF THE GEOLOGICAL RECORD.

DEDICATED TO THE MEMORY OF

JOACHIN BARRANDE,

ONE OF THE MOST SUCCESSFUL LABOURERS

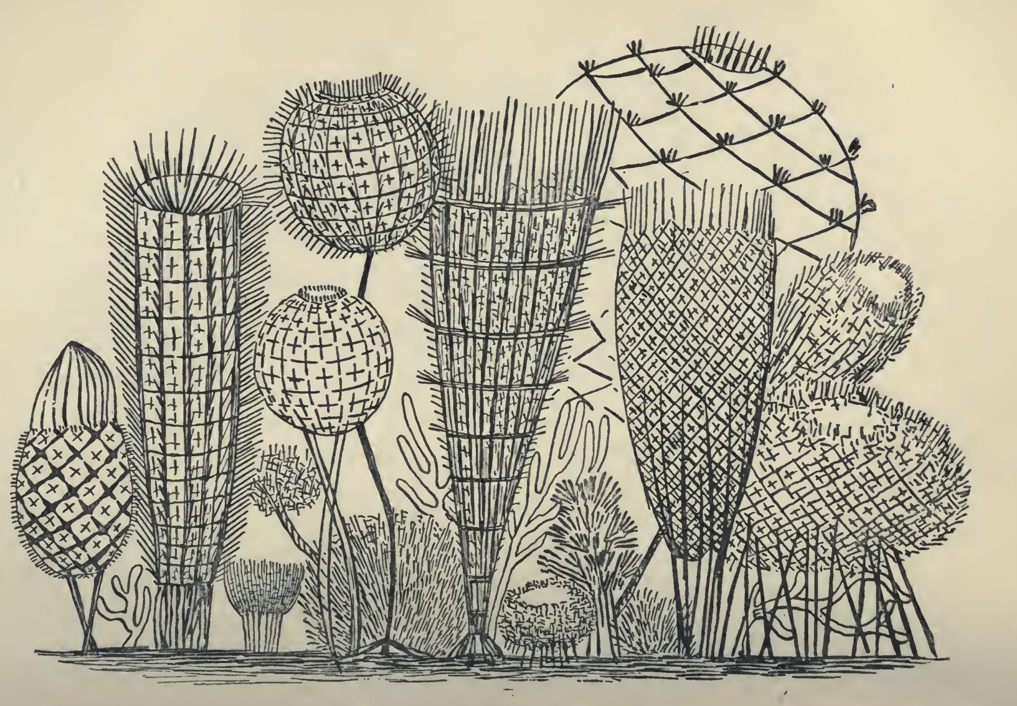
IN THE

COMPLETION OF THE HISTORY OF LIFE

IN ITS EARLIER STAGES.

Nature of the Imperfection — Questions as to its arising from Want of Continuity, from Lack of Preservation, from Imperfect Collecting. Examples—Land Snails, Carboniferous Batrachians, Palæozoic Sponges, Pleistocene Shells, Devonian and Carboniferous Plants — Comparative Perfection in the Case of Marine Shells, etc.—Possible Cambrian Squids—Questions as to Want of First Chapters of the Record—Practical Conclusions





CAMBRO-SILURIAN SPONGES RESTORED.—*Protospongia*, *Acanthodictya*, *Cyathospongia*, *Lasiothrix*, *Hali-*

CHAPTER III.

THE IMPERFECTION OF THE GEOLOGICAL RECORD.

COMPLAINTS of the imperfection of the geological record are rife among those biologists who expect to find continuous series of fossils representing the gradual transmutation of species. No doubt these gaps are in some cases portentous, and unfortunately they often occur just where it is most essential to certain general conclusions that they should be filled up. Instead, however, of making vague lamentations on the subject, it is well to inquire to what causes these gaps may be due, to what extent they invalidate the completeness of geological history for scientific purposes, and how they may best be filled.

Here we may first remark that it is not so much the physical record of geology that is imperfect as the organic record. Ever since the time of Hutton and Playfair we have learned that the processes of mineral detrition and deposition are continuous, and have been so throughout geological time. The erosion of the land is constantly going on, every shower carries its tribute of earthy matter toward the sea, and every wave that strikes against a beach or cliff does some work toward the grinding of shells, pebbles or stone. Thus, everywhere around our continents there is a continuous deposition of beds of earthy matter, and it is this which, when elevated into new land, has given us our chronological series of geological formations. True, the elevating process is not continuous, but, so

far as we know, intermittent; but it has been so often repeated that we have no reason to doubt that the wasting continents afford a complete series of aqueous deposits, since the time when the dry land first appeared.

In recent years the *Challenger* expedition and similar dredgings have informed us of still another continuity of deposition in the depths of the ocean. There, where no detritus from the land, or only a very little fine volcanic ash or pumice has ever reached, we have, going on from age to age, a deposit of the hard parts of abyssal animals and of those that swim in the open sea; so that if it were possible to bore or sink a shaft in some parts of the ocean, we should find not only a continuous bed, but a continuous series of pelagic life from the Laurentian to the present day. Thus we have continuous physical records, could we but reach or completely put them together, and eliminate the disturbing influence of merely local vicissitudes. It is when we begin to search the geological formations for fossils, that imperfection in our record first becomes painfully manifest.

In the case of many groups of marine animals, as, for example, the shell-fish and the corals, and I may add the bivalve crustaceans, so admirably worked up by my friend Prof. Rupert Jones, we have very complete series. With the and snails the case is altogether different. As stated in another paper of this series, a few species of these animals appear in the later Palæozoic age, and after that they have no successors known to us in all the great periods covered by the Permian, the Trias, and the earlier Jurassic. A few air-breathing water-snails appear in the upper Jurassic, and true land snails are not met with again until the Tertiary. Were there no land snails in this vast lapse of time? Have we two successive creations, so to speak, of these creatures at distant intervals? Were they only diminished in numbers and distribution in the intervening time? Is the hiatus owing merely

to the unlikelihood of such shells being preserved? Or is it owing to the lack of diligence and care in collecting?

In this particular case we are, no doubt, disposed to say that the series must have been continuous. But we cannot be sure of this. In whatever way a few species of land snails were so early introduced in the time of the Devonian or of the Coal formation, if from physical vicissitudes or lack of proper pabulum they became extinct, there is no reason known to us why, when circumstances again became favourable, they should not be reintroduced in the same manner as at first, whether by development from allied types or otherwise. The fact that the few Devonian and Carboniferous species are very like those that still exist, perhaps makes against this supposition, but does not exclude it. If we suppose that new forms of life of low grade are introduced from time to time in the course of the geological ages, and if we adopt the Darwinian hypothesis of evolution, we arrive, as Naegeli has so well pointed out, at the strange paradox, that the highest forms of life must be the oldest of all, since they will be the descendants of the earliest of the lower animals, whereas the animals now of low grade may have been introduced later, and may not have had time to improve. But all our attempts to reduce nature to one philosophic expression necessarily lead to such paradoxes.

On the other hand, the chances of the preservation of land snails in aqueous deposits are vastly less than those in favour of the preservation of aquatic species. The first Carboniferous species found[1] had been preserved in the very exceptional circumstances afforded by the existence of hollow trunks of Sigillariæ on the borders of the Coal formation flats, and the others subsequently found were in beds no doubt receiving the drainage of neighbouring land areas. Still it is not uncommon on the modern sea-shore, anywhere near the mouths of rivers, to find a few freshwater shells here and there. The

[1] *Pupa vetusta* of the Nova Scotia coal formation.

carbonaceous beds of the Trias, the fossil soils of the Portland series, the estuarine Wealden beds would seem to be as favourably situated as those of the coal formation for preserving land shells, though possibly the flora of the Mesozoic was less suitable for feeding such creatures than that of the Coal period, and they may consequently have become few and local. After all, perhaps more diligent collecting and more numerous collectors might succeed, and may succeed in the future, in filling this and similar gaps.

It is a great mistake to suppose that discoveries of this kind are made by chance. It is only by the careful and painstaking examination of much material that the gaps in the geological record can be filled up, and I propose in the sequel of this article to note a few instances, in a country where the range of territory is altogether out of proportion to the number of observers, and which have come within my own knowledge.

It was not altogether by accident that Sir C. Lyell and the writer discovered a few reptilian bones and a land snail in breaking up portions of the material filling an erect Sigillaria in the South Joggins coal measures. We were engaged in a deliberate survey of the section, to ascertain as far as might be the conditions of accumulation of coal, and one point which occurred to us was to inquire as to the circumstances of preservation of stumps of forest trees in an erect position, to trace their roots into the soils on which they stood, and to ascertain the circumstances in which they had been buried, had decayed, and had been filled with mineral matter. It was in questioning these erect trees on such subjects—and this not without some digging and hammering—that we made the discovery referred to.

But we found such remains only in one tree, and they were very imperfect, and indicated only two species of batrachians and one land snail. There the discovery might have rested. But I undertook to follow it up. In successive visits to the

coast, a large number of trees standing in the cliff and reefs, or fallen to the shore, were broken up and examined, the result being to discover that, with one unimportant exception, the productive trees were confined to one of the beds at Coal Mine Point, that from which the original specimens had been obtained. Attention was accordingly concentrated on this, and as many as thirty trees were at different times extracted from it, of which rather more than one-half proved more or less productive. By these means bones representing about sixty specimens and twelve species were extracted, besides numerous remains of land shells, millipedes, and scorpions. In this way a very complete idea was obtained of the land life, or at least of the smaller land animals, of this portion of the coal formation of Nova Scotia. It is not too much to say that if similar repositories could be found in the succeeding formations, and properly worked when found, our record of the history of land quadrupeds might be made very complete.

When in 1855 I changed my residence from Nova Scotia to Montreal, and so was removed to some distance from the carboniferous rocks which I had been accustomed to study, I naturally felt somewhat out of place in a Cambro-Silurian district, more especially as my friend Billings had already almost exhausted its fossils. I found, however, a congenial field in the Pleistocene shell beds; more especially as I had given some attention to recent marine animals when on the sea coast. The very perfect series of Pleistocene deposits in the St. Lawrence valley locally contain marine shells from the bottom of the till or boulder clay up to the overlying sands and gravels. The assemblage was a more boreal one than that on the coast of Nova Scotia, though many of the species were the same, and both the climatal and bathymetrial conditions differed in different parts of the Pleistocene beds themselves. The gap in the record here could at that time be filled up only by collecting recent shells. In addition to what could be obtained

by exchanging with naturalists who had collected in Greenland, Labrador, and Norway, I employed myself, summer after summer, in dredging both on the south and north shore of the St. Lawrence, until able at length to discover in a living state, but under different conditions as to temperature and depth, nearly every species found in the beds on the land, from the lower boulder clay to the top of the formation, and from the sea-level to the beds six hundred feet high on the hills. Not only so: I could ascertain in certain places and conditions all the peculiar varieties of the species, and the special modes of life which they indicated. Thus, in the cases of the Peter Redpath Museum, and in notes on the Post-pliocene of Canada, the gap between the Modern and the Glacial age was completely filled up in so far as Canadian marine species are concerned. The net result was, as I have elsewhere stated, that no change other than varietal had occurred.

In studying the fossil plants of the Carboniferous, so abundant in the fine exposures of the coal formation in Nova Scotia, two defects struck me painfully. One was the fragmentary and imperfect state of the specimens procurable. Another was the question, What preceded these plants in the older rocks? The first of these was to be met only by thorough exploration. When a fragment of a plant was disclosed it was necessary to inquire if more existed in the same bed, and to dig, or blast away or break up the rock, until some remaining portions were disclosed. In this way it has been possible to obtain entire specimens of many trees of the Carboniferous; and to such an extent has the laborious and somewhat costly process been effectual, that more species of carboniferous trees are probably known in their entire forms from the Coal formations of Nova Scotia than from any other part of the world. I have been amused to find that so little are experiences of this kind known to some of my *confrères* abroad, that they

are disposed to look with scepticism on the information obtained by this laborious but certain process, and to suppose that they are being presented with imaginary "restorations." I think it right here to copy a remark of a German botanist, who has felt himself called to criticise my work: "Dawson's description of the genus (*Psilophyton*) rests chiefly on the impression made on him in his repeated researches," etc. "He puts us off with an account of the general idea which he has drawn from the study of them." This is the remark of a closet naturalist, with reference to the kind of work above referred to, which, of course, cannot be represented in its entirety in figures or hand specimens.[1]

As to the precursors of the Carboniferous flora, in default of information already acquired, I proceeded to question the Erian or Devonian rocks of Canada, in which Sir William Logan had already found remains of plants which had not, however, been studied or described. Laboriously coasting along the cliffs of Gaspé and the Baie des Chaleurs, digging into the sandstones of Eastern Maine, and studying the plants collected by the New York Survey, I began to find that there was a rich Devonian flora, and that, like that of the Carboniferous, it presented different stages from the base to the summit of the formation. But here a great advance was made in a somewhat unexpected way. My then young friends, the late Prof. Hartt and Mr. Matthew, of St. John, had found a few remains of plants in the Devonian, or at least pre-Carboniferous beds of St. John, which were placed in my hands for description. They were so novel and curious that inquiry was stimulated, and these gentlemen, with some friends of similar tastes, explored the shales exposed in the reefs near St. John, and when they found the more productive beds, broke them up by

[1] Solms-Laubach, "Fossil Botany." A pretentious book, which should not have been translated into English without thorough revision and correction.

actual quarrying operations in such a way that they soon obtained the richest Devonian plant collections ever known. I think I may truly say that these young and enthusiastic explorers worked the St. John plant-beds in a manner previously unexampled in the world. Their researches were not only thus rewarded, but incidentally they discovered the first known Devonian insects, which could not have been found by a less painstaking process, and one of them discovered what I believe to be the oldest known land shell. Still more, their studies led to the separation from the Devonian beds of the Underlying Cambrian slates, previously confounded with them; and this, followed up by the able and earnest work of Mr. Matthew, has carried back our knowledge of the older rocks in Canada several stages, or as far as the earliest Cambrian previously known in Europe, but not before fully recognised in America, and has discovered in these old rocks the precursors of many forms of life not previously traced so far back.

The moral of these statements of fact is that the imperfections of the record will yield only to patient and painstaking work, and that much is in the power of local amateurs. I would enforce this last statement by a reference to a little research, in which I have happened to take part at a summer resort on the Lower St. Lawrence, at which I have from time to time spent a few restful vacation weeks. Little Metis is on the Quebec Group of Sir William Logan, that peculiar local representative of the lower part of the Cambro-Silurian and Upper Cambrian formations which stretches along the south side of the St. Lawrence all the way from Quebec to Cape Rosier, near Gaspé, a distance of five hundred miles. This great series of rocks is a jumble of deposits belonging at that early time to the marginal area of what is now the American continent, and indicating the action not merely of ordinary causes of aqueous deposit, but of violent volcanic ejections,

accompanied perhaps by earthquake waves, and not improbably by the action of heavy coast ice. The result is that mud rocks now in the form of black, grey, and red shales and slates alternate with thick and irregular beds of hard sandstone, sometimes so coarse that it resembles the angular *débris* of the first treatment of quartz in a crusher. With these sandstones are thick and still more irregular conglomerates formed of pebbles and boulders of all sizes, up to several feet in diameter, some of which are of older limestones containing Cambrian fossils, while others are of quartzite or of igneous or volcanic rocks.

The whole formation, as presented at Metis, is of the most unpromising character as regards fossils, and after visiting the place for ten years, and taking many long walks along the shore and into the interior, and scrutinising every exposure, I had found nothing more interesting than a few fragments of graptolites, little zoophytes, ancient representatives of our sea mosses, and which are quite characteristic of several portions of the Quebec Group. With these were some marks of fucoids and tracks or burrows of worms. The explorers of the Geological Survey had been equally unsuccessful.

Quite accidentally a new light broke upon these unpromising rocks. My friend, Dr. Harrington, strolling one day on the shore, sat down to rest on a stone, and picked up a piece of black slate lying at his feet. He noticed on it some faintly traced lines which seemed peculiar. He put it in his pocket and showed it to me. On examination with a lens it proved to have on it a few spicules of a hexactinellid sponge—little crosses forming a sort of mesh or lattice-work similar to that which Salter had many years before found in the Cambrian rocks of Wales, and had named *Protospongia*—the first sponge. The discovery seemed worth following up, and we took an early opportunity of proceeding to the place, where, after some search, we succeeded in tracing the loose pieces to a ledge of

shale on the beach, where there was a little band, only about an inch thick, stored with remains of sponges, a small bivalve shell and a slender branching seaweed. This was one small layer in reefs of slate more than one hundred feet thick. We subsequently found two other thin layers, but less productive. Tools and workmen were procured, and we proceeded to quarry in the reef, taking out at low tide as large slabs as possible of the most productive layer, and carefully splitting these up. The results, as published in the Transactions of the Royal Society of Canada,[1] show more than twelve species of siliceous sponges belonging to six genera, besides fragments indicating other species, and all of these living at one time on a very limited space of what is practically a single surface of muddy sea-bottom.[2] The specimens show the parts of these ancient sponges much more perfectly than they were previously known, and indeed, enable many of them to be perfectly restored. They for the first time connect the modern siliceous sponges of the deep sea with those that flourished on the old sea-bottom of the early Cambro-Silurian, and thus bridge over a great gap in the history of this low form of life, showing that the principles of construction embodied in the remarkable and beautiful siliceous sponges, like Euplectella, the "Venus flower-basket," now dredged from the deep sea, were already perfectly carried out in this far-back beginning of life. This little discovery further indicates that portions of the older Palæozoic sea-bottoms were as well stored with a varied sponge life as those of any part of the modern ocean. I figure [3] a number of species, remains of all of which may be gathered from a few yards of a single surface at Little Metis. The multitude of interesting details embodied in all this it is impossible to enter into here, but may be judged of from

[1] Additional collections made in 1892 show two or three additional species, one of them the type of a new and remarkable genus.

[2] 1889, section iv. p. 39.

[3] Frontispiece to chapter.

the forms reproduced. These examples tend to show that the imperfection of the record may not depend on the record itself, but on the incompleteness of our work. We must make large allowance for imperfect collecting, and especially for the too prevalent habit of remaining content with few and incomplete specimens, and of grudging the time and labour necessary to explore thoroughly the contents of special beds, and to work out all the parts of forms found more or less in fragments.

The point of all this at present is that patient work is needed to fill up the breaks in our record. A collector passing along the shore at Metis might have picked up a fragment of a fossil sponge, and recorded it as a fossil, or possibly described the fragment. This fact alone would have been valuable, but to make it bear its full fruit it was necessary to trace the fragment to its source, and then to spend time and labour in extracting from the stubborn rock the story it had to tell. Instances of this kind crowd on my memory as coming within my own experience and observation. It is hopeful to think that the record is daily becoming less imperfect; it is stimulating to know that so much is only waiting for investigation. The history never can be absolutely complete. Practically, to us it is infinite. Yet every series of facts known may be complete in itself for certain purposes, however many gaps there may be in the story. Even if we cannot find a continuous series between the snails of the Coal formation or the sponges of the Quebec Group and their successors to-day, we can at least see that they are identical in plan and structure, and can note the differences of detail which fitted them for their places in the ancient or the modern world. Nor need we be too discontented if the order of succession, such as it is, does not exactly square with some theories we may have formed. Perhaps it may in the end lead us to greater and better truths.

Another subject which merits attention here is the evidence which mere markings or other indications may sometimes give

as to the existence of unknown creatures, and thus may be as important to us as the footprints of Friday to Robinson Crusoe. As I have been taking Canadian examples, I may borrow one here from Mr. Matthew, of St. John, New Brunswick.

He remarks in one of his papers the manner in which the Trilobites of the early Cambrian are protected with defensive spines, and asks against what enemies they were intended to guard. That there were enemies is further proved by the occurrence of Coprolites or masses of excrement, oval or cylindrical in form, and containing fragments of shells of Trilobites, of Pteropods (Hyolithes) and of Lingula. There must therefore have been marine animals of considerable size, which preyed on Trilobites. Dr. Hunt and myself have recorded similar facts from the Upper-Cambrian and Cambro-Silurian of the Province of Quebec. No remains, however, are known of animals which could have produced such coprolites, except, indeed, some of the larger worms of the period, and they seem scarcely large enough. In these circumstances Mr. Matthew falls back on certain curious marks or scratches with which large surfaces of these old rocks are covered, and which he names Ctenichnites or "Comb tracks." These markings seem to indicate the rapid motion of some animal touching the bottom with fins or other organs; and as we know no fishes in these old rocks, the question recurs, What could it have been? From the form and character of the markings Mr. Matthew infers (1) That these animals lived in "schools," or were social in their habits; (2) That they had a rapid, direct, darting motion; (3) That they had three or four (at least) flexible arms; (4) That these arms were furnished with hooks or spines; (5) That the creatures swam with an easy motion, so that sometimes the arms of one side touched the bottom, sometimes those of the other. These indications point to animals allied to the modern squids or cuttlefishes, and as these animals may have had no hard parts capable of pre-

servation, except their horny beaks, nothing might remain to indicate their presence except these marks on the bottom. Mr. Matthew therefore conjectures that there may have been large cuttlefishes in the Cambrian. Since, however, these are animals of very high rank in their class, and are not certainly known to us till a very much later period, their occurrence in these old rocks would be a very remarkable and unexpected fact.

A discovery made by Walcott in the Western States since Mr. Matthew's paper was written, throws fresh light on the question. Remains of fishes have been found by the former in the Cambro Silurian rocks nearly as far back as Mr. Matthew's comb-tracks. Besides this, Pander in Russia has found in these old rocks curious teeth, which he refers conjecturally to fishes (Conodonts). Why may there not have been in the Cambrian large fishes having, like the modern sharks, cartilage or gristle instead of bone—perhaps destitute of scales, and with small teeth which have not yet been detected. The fin rays of such fishes may have left the comb tracks, and in support of this I may say that there are in the Lower Carboniferous of Horton Bluff, in Nova Scotia, very similar tracks in beds holding many remains of fishes. Whichever view we adopt we see good evidence that there were in the early Cambrian animals of higher grade than we have yet dreamt of. Observe, however, that if we could complete the record in this point it would only give us higher forms of life at an earlier time, and so push farther back their possible development from lower forms. I fear, indeed, that I can hold out little hopes to the evolutionists that a more complete geological record would help them in any way. It would possibly only render their position more difficult.

But the saddest of all the possible defects of the geological record is that it may want the beginning, and be like the Bible of some of the German historical critics, from which they

eliminate as mythical everything before the time of the later Hebrew kings. Our attention is forcibly called to this by the condition of the fauna of the earliest Cambrian rocks. The discoveries in these in Wales, in Norway, and in America show us that the seas of this early period swarmed with animals representing all the great types of invertebrate marine life. We have here highly organized Crustaceans, Worms, Mollusks and other creatures which show us that in that early age all these distinct forms of life were as well separated from each other as in later times, that eyes of different types, jointed limbs with nerves and muscles, and a vast variety of anatomical contrivances wêre as highly developed as at any subsequent time.[1] To a Darwinian evolutionist this means nothing less than that these creatures must have existed through countless ages of development from their imagined simple ancestral form or forms—how long it is impossible to guess, since, unless change was more speedy in the infancy of the earth, the term of ages required must have far exceeded that from the Cambrian to the Modern. Yet, to represent all this we have absolutely nothing except Eozoon in its solitary grandeur, and a

[1] Walcott and Matthew record more than 160 species of 67 genera, including Sponges, Zoophytes, Echinoderms, Brachiopods, Bivalve and Univalve shellfishes, Trilobites and other Crustaceans from the Lower Cambrian of the United States of America and Canada alone ; and these are but a portion of the inhabitants of the early Cambrian seas. There is a rich Scandinavian fauna of the same early date, and in England and Wales, Salter, Hicks and Lapworth have described many fossils of the basal Cambrian. From year to year, also, discoveries of fossil remains are being made, both in America and Europe, in beds of older date than those previously known to be fossiliferous. At present, however, these remains are still few and imperfectly known, and it is not in all cases certain whether the beds in which they occur are pre-Cambrian or belong to the lowest members of that great system. It is unfortunate that so many of the strata between the Laurentian and the Cambrian seem to be of a character little likely to contain fossils; being littoral deposits produced in times of much physical disturbance. Yet there must have been contemporaneous beds of a different character, which may yet be discovered.

few other forms, possibly of Protozoa and worms. An imaginary phylogeny of animal life from Monads to Trilobites would be something as long as the whole geological history. Yet it would be almost wholly imaginary, for the record of the rocks tells little or nothing. In face of such an imperfection as this, geologists should surely be humble, and make confession of ignorance to any extent that may be desired. Yet we may at least, with all humility and self-abasement, ask our critics how they know that this great blank really exists, and whether it may not be possible that the swarming life of the early Cambrian may, after all, have appeared suddenly on the stage in some way as yet unknown to us and to them.

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THE HISTORY OF THE NORTH ATLANTIC.

DEDICATED TO THE MEMORY OF

PROF. JOHN PHILLIPS,

OF OXFORD,

ONE OF THE MOST ABLE, EARNEST, AND GENIAL OF
ENGLISH GEOLOGISTS;

AND OF OTHER EMINENT SCIENTIFIC MEN, NOW PASSED AWAY,
WHO SUPPORTED HIM AS
PRESIDENT OF THE BRITISH ASSOCIATION, AT ITS
MEETING IN BIRMINGHAM, IN 1865.

Distribution of Land and Water—Causes of Irregularities of the Surface Crust and Interior—Position of Continents—Past History of the Atlantic—Its Relations to Life—Its Future





Map of the North Atlantic, showing depths from 4,000 fathoms upward

CHAPTER IV.

THE HISTORY OF THE NORTH ATLANTIC.

I HAD the pleasure of being present at the meeting of the British Association at Birmingham, in 1865: a meeting attended by an unusually large number of eminent geologists, under the presidency of my friend Phillips. I had the further pleasure of being his successor at the meeting in the same place, in 1886; and the subject of this chapter is that to which I directed the attention of the Association in my Presidential address. I fear it is a feeble and imperfect utterance compared with that which might have been given forth by any of the great men present in 1865, and who have since left us, could they have spoken with the added knowledge of the intervening twenty years.

The geological history of the Atlantic appeared to be a suitable subject for a trans-Atlantic president, and to a Society which had vindicated its claim to be British in the widest sense by holding a meeting in Canada, while it was also meditating a visit to Australia—a visit not yet accomplished, but in which it may now meet with a worthy daughter in the Australian Association formed since the meeting of 1886. The subject is also one carrying our thoughts very far back in geological time, and connecting itself with some of the latest and most important discussions and discoveries in the science of the earth, furnishing, indeed, too many salient points to be profitably occupied in a single chapter.

If we imagine an observer contemplating the earth from a

convenient distance in space, and scrutinizing its features as it rolls before him, we may suppose him to be struck with the fact that eleven-sixteenths of its surface are covered with water, and that the land is so unequally distributed that from one point of view he would see a hemisphere almost exclusively oceanic, while nearly the whole of the dry land is gathered in the opposite hemisphere. He might observe that large portions of the great oceanic areas of the Pacific and Antarctic Oceans are dotted with islands—like a shallow pool with stones rising above its surface—as if the general depth were small in comparison with the area. Other portions of these oceans he might infer, from the colour of the water and the absence of islands, cover deep depressions in the earth's surface. He might also notice that a mass or belt of land surrounds each pole, and that the northern ring sends off to the southward three vast tongues of land and of mountain chains, terminating respectively in South America, South Africa, and Australia, towards which feebler and insular processes are given off by the antarctic continental mass. This, as some geographers have observed,[1] gives a rudely three-ribbed aspect to the earth, though two of the ribs are crowded together, and form the Eurasian mass or double continent, while the third is isolated in the single continent of America. He might also observe that the northern girdle is cut across, so that the Atlantic opens by a wide space into the Arctic Sea, while the Pacific is contracted toward the north, but confluent with the Antarctic Ocean. The Atlantic is also relatively deeper and less cumbered with islands than the Pacific, which has the highest ridges near its shores, constituting what some visitors to the Pacific coast of America have not inaptly called the "back of the world," while the wider slopes face the narrower ocean. The Pacific and Atlantic, though both depressions or flat-

[1] Dana, "Manual of Geology," introductory part. Green, "Vestiges of a Molten Globe," has summed up these facts.

tenings of the earth, are, as we shall find, different in age, character, and conditions; and the Atlantic, though the smaller, is the older, and, from the geological point of view, in some respects, the more important of the two ; while, by virtue of its lower borders and gentler slope, it is, though the smaller basin, the recipient of the greater rivers, and of a proportionately great amount of the drainage of the land.[1]

If our imaginary observer had the means of knowing anything of the rock formations of the continents, he would notice that those bounding the North Atlantic are, in general, of great age—some belonging to the Laurentian system. On the other hand, he would see that many of the mountain ranges along the Pacific are comparatively new, and that modern igneous action occurs in connection with them. Thus he might see in the Atlantic, though comparatively narrow, a more ancient feature of the earth's surface; while the Pacific belongs to more modern times. But he would note, in connection with this, that the oldest rocks of the great continental masses are mostly toward their northern ends; and that the borders of the northern ring of land, and certain ridges entending southward from it, constitute the most ancient and permanent elevations of the earth's crust, though now greatly surpassed by mountains of more recent age nearer the equator, so that the continents of the northern hemisphere seem to have grown progressively from north to south.

If the attention of our observer were directed to more modern processes, he might notice that while the antarctic continent freely discharges its burden of ice to the ocean north of it, the arctic ice has fewer outlets, and that it mainly discharges itself through the North Atlantic, where also the great mass of Greenland stands as a huge condenser and cooler,

[1] Mr. Mellard Reade, in two Presidential addresses before the Geological Society of Liverpool, has illustrated this point and its geological consequences.

unexampled elsewhere in the world, throwing every spring an immense quantity of ice into the North Atlantic, and more especially into its western part. On the other hand, he might learn from the driftage of weed and the colour of the water, that the present great continuous extension and form of the American continent tend to throw northward a powerful branch of the equatorial current, which, revolving around the North Atlantic, counteracts the great flow of ice which otherwise would condemn it to a perpetual winter.

Further, such an observer would not fail to notice that the ridges which lie along the edges of the oceans and the ebullitions of igneous matter which proceed, or have proceeded from them, are consequences of the settling downward of the great oceanic depressions, a settling ever intensified by their receiving more and more of deposit on their surfaces; and that this squeezing upward of the borders of these depressions into folds has been followed or alternated with elevations and depressions without any such folding, and proceeding from other causes. On the whole, it would be apparent that these actions are more vigorous now at the margins of the Pacific area, while the Atlantic is backed by very old foldings, or by plains and slopes from which it has, so to speak, dried away without any internal movement. Thus it would appear that the Pacific is the great centre of earth-movement, while the Atlantic trench is the more potent regulator of temperature, and the ocean most likely to be severely affected in this respect by small changes of its neighbouring land. Last of all, an observer, such as I have supposed, would see that the oceans are the producers of moisture and the conveyors of heat to the northern regions of the world, and that in this respect and in the immense condensation and delivery of ice at its north end, the Atlantic is by far the more active, though the smaller of the two.

So much could be learned by an extra-mundane observer;

but unless he had also enjoyed opportunities of studying the rocks of the earth in detail and close at hand, or had been favoured by some mundane friend with a perusal of "Lyell's Elements," or "Dana's Manual," he would not be able to appreciate as we can the changes which the Atlantic has seen in geological time, and in which it has been a main factor. Nor could he learn from such superficial observation certain secrets of the deep sea, which have been unveiled by the sounding lead, the inequalities of the ocean basin, its few profound depths, like inverted mountains or table-lands, its vast nearly flat abyssmal floor, and the sudden rise of this to the hundred fathom line, forming a terrace or shelf around the sides of the continents. These features, roughly represented in the map prefixed, he would be unable to perceive.

Before leaving this broad survey, we may make one further remark. An observer, looking at the earth from without, would notice that the margins of the Atlantic and the main lines of direction of its mountain chains are north-east and south-west, and north-west and south-east, as if some early causes had determined the occurrence of elevations along great circles of the earth's surface tangent to the polar circles.

We are invited by the preceding general glance at the surface of the earth to ask certain questions respecting the Atlantic. (1) What has at first determined its position and form? (2) What changes has it experienced in the lapse of geological time? (3) What relations have these changes borne to the development of life on the land and in the water? (4) What is its probable future?

Before attempting to answer these questions, which I shall not take up formally in succession, but rather in connection with each other, it is necessary to state, as briefly as possible, certain general conclusions respecting the interior of the earth. It is popularly supposed that we know nothing of this beyond a superficial crust perhaps averaging 50,000 to 100,000 feet in

thickness. It is true we have no means of exploration in the earth's interior, but the conjoined labours of physicists have now proceeded sufficiently far to throw much inferential light on the subject, and to enable us to make some general affirmations with certainty; and these it is the more necessary to state distinctly, since they are often treated as mere subjects of speculation and fruitless discussion.

(1) Since the dawn of geological science, it has been evident that the crust on which we live must be supported on a plastic or partially liquid mass of heated rock, approximately uniform in quality under the whole of its area. This is a legitimate conclusion from the wide distribution of volcanic phenomena, and from the fact that the ejections of volcanoes, while locally of various kinds, are similar in every part of the world. It led to the old idea of a fluid interior of the earth, but this seems now generally abandoned, and this interior heated and plastic layer is regarded as merely an under-crust, resting on a solid nucleus.[1]

(2) We have reason to believe, as the result of astronomical investigations,[2] that, notwithstanding the plasticity or liquidity of the under-crust, the mass of the earth—its nucleus as we may call it—is practically solid and of great density and hardness. Thus we have the apparent paradox of a solid yet fluid earth; solid in its astronomical relations, liquid or

[1] I do not propose to express any definite opinion as to this question, as either conclusion will satisfy the demands of geology. It would seem, however, that astronomers now admit a slight periodical deformation of the crust. See Lord Kelvin's Anniversary Address to Royal Society, 1892.

[2] Hopkins, Mallet, Lord Kelvin, and Prof. G. H. Darwin maintain the solidity and rigidity of the earth on astronomical grounds; but different conclusions have been reached by Fisher, Hennesey, Delaunay, and Airy. In America, Hunt, Barnard and Crosby, Dutton, Le Conte and Wadsworth have discussed these questions. Bonney has suggested that a mass may be slowly mobile under long-continued pressure, while rigid with reference to more sudden movements.

plastic for the purposes of volcanic action and superficial movements.

(3) The plastic sub-crust is not in a state of dry igneous fusion, but in that condition of aqueo-igneous or hydrothermic fusion which arises from the action of heat on moist substances, and which may either be regarded as a fusion or as a species of solution at a very high temperature. This we learn from the phenomena of volcanic action, and from the composition of the volcanic and plutonic rocks, as well as from such chemical experiments as those of Daubrée, and of Tilden, and Shenstone.[1] It follows that water or steam, as well as rocky matter, may be ejected from the under-crust.

(4) The interior sub-crust is not perfectly homogeneous, but may be roughly divided into two layers or magmas, as they have been called; an upper, highly silicious or acidic, of low specific gravity and light-coloured, and corresponding to such kinds of plutonic and volcanic rocks as granite and trachyte; and a lower, less silicious or more basic, more dense, and more highly charged with iron, and corresponding to such igneous rocks as the dolerites, basalts, and kindred lavas. It is interesting here to note that this conclusion, elaborated by Durocher and Von Waltershausen, and usually connected with their names, appears to have been first announced by John Phillips, in his "Geological Manual," and as a mere common-sense deduction from the observed phenomena of volcanic action and the probable results of the gradual cooling of the earth. It receives striking confirmation from the observed succession of acidic and basic volcanic rocks of all geological periods and in all localities. It would even seem, from recent spectroscopic investigations of Lockyer, that there is evidence of a similar succession of magmas in the heavenly bodies, and the discovery by Nordenskiöld of native iron in Greenland

[1] *Phil. Trans.*, 1884. Also Crosby in *Proc. Boston Soc. Nat. Hist.*, 1883.

basalts, affords a probability that the inner magma is in part metallic, and possibly, that vast masses of unoxidised metals exist in the central portion of the earth.

(5) Where rents or fissures form in the upper crust, the material of the lower crust is forced upward by the pressure of the less supported portions of the former, giving rise to volcanic phenomena either of an explosive or quiet character, as may be determined by contact with water. The underlying material may also be carried to the surface by the agency of heated water, producing those quiet discharges which Hunt has named crenitic. It is to be observed here that explosive volcanic phenomena, and the formation of cones, are, as Prestwich has well remarked, characteristic of an old and thickened crust; quiet ejection from fissures and hydrothermal action may have been more common in earlier periods and with a thinner over-crust. This is an important consideration with reference to those earlier ages referred to in chapter second.

(6) The contraction of the earth's interior by cooling and by the emission of material from below the over-crust, has caused this crust to press downward, and therefore laterally, and so to effect great bends, folds, and plications; and these, modified subsequently by surface denudation, and the piling of sediments on portions of the crust, constitute mountain chains and continental plateaus. As Hall long ago pointed out,[1] such lines of folding have been produced more especially where thick sediments had been laid down on the sea-bottom, and where, in consequence, internal expansion of the crust had occurred from heating below. Thus we have here another apparent paradox, namely, that the elevations of the earth's crust occur in the places where the greatest burden of de-

[1] Hall (American Association Address, 1857, subsequently republished, with additions, as "Contributions to the Geological History of the American Continent"), Mallet, Rogers, Dana, La Conte, etc.

tritus has been laid down upon it, and where, consequently, the crust has been softened and depressed. We must beware, in this connection, of exaggerated notions of the extent of contraction and of crumpling required to form mountains. Bonney has well shown, in lectures delivered at the London Institution, that an amount of contraction, almost inappreciable in comparison with the diameter of the earth, would be sufficient; and that, as the greatest mountain chains are less than $\frac{1}{600}$th of the earth's radius in height, they would, on an artificial globe a foot in diameter, be no more important than the slight inequalities that might result from the paper gores overlapping each other at the edges. This thinness of the crushed crust agrees with the deductions of physical science as to the shallowness of the superficial layer of compression in a cooling globe. It is perhaps not more than five miles in thickness. A singular proof of this is seen by the extension of straight cracks filled with volcanic rock in the Laurentian districts of Canada.[1] The beds of gneiss and associated rocks are folded and crumpled in a most complex manner, yet they are crossed by these faults, as a crack in a board may tear a sheet of paper or a thin veneer glued on it. We thus see that the crumpled Laurentian crust was very thin, while the uncrushed sub-crust determined the line of fracture.

(7) The crushing and sliding of the over-crust implied in these movements raise some serious questions of a physical character. One of these relates to the rapidity or slowness of such movements, and the consequent degree of intensity of the heat developed, as a possible cause of metamorphism of rocks. Another has reference to the possibility of changes in the equilibrium of the earth itself, as resulting from local collapse and ridging. These questions in connection with the

[1] As, for instance, the great dyke running nearly in a straight line from near St. Jerome along the Ottawa to Templeton, on the Ottawa, and beyond, a distance of more than a hundred miles.

present dissociation of the axis of rotation from the magnetic poles, and with changes of climate, have attracted some attention,[1] and probably deserve further consideration on the part of physicists. In so far as geological evidence is concerned, it would seem that the general association of crumpling with metamorphism indicates a certain rapidity in the process of mountain-making, and consequent development of heat; and the arrangement of the older rocks around the Arctic basin forbids us from assuming any extensive movement of the axis of rotation, though it does not exclude changes to a limited extent.

(8) It appears from the above that mountains and continental elevations may be of three kinds. (*a*) They may consist of material thrown out of volcanic rents, like earth out of a mole burrow. Mountains like Vesuvius and Ætna are of this kind. (*b*) They may be parts of wide ridges or chains variously cut and modified by rains and rivers. The Lebanon and the Catskill Mountains are cases in point. (*c*) They may be lines of crumpling by lateral pressure. The greatest mountains, like the Cordillera, the Alps, and the Appalachians are of this kind, and such mountains may represent lateral pressure occurring at various times, and whose results have been greatly modified subsequently.

I wish to formulate these principles as distinctly as possible, and as the result of all the long series of observations, calculations, and discussions since the time of Werner and Hutton, and in which a vast number of able physicists and naturalists have borne a part, because they may be considered as certain deductions from our actual knowledge, and because they lie at the foundation of a rational physical geology.

We may roughly popularise these deductions by comparing the earth to a drupe or stone-fruit, such as a plum or peach

[1] See recent papers of Oldham and Fisher, in *Geological Magazine*, and *Philosophical Magazine*, July, 1886. Also Péroche, "Revol. Polaires." Paris, 1886.

somewhat dried up. It has a large and intensely hard stone and kernel, a thin pulp made up of two layers, an inner, more dense and dark-coloured, and an outer, less dense and lighter-coloured. These constitute the under-crust. On the outside it has a thin membrane or over-crust. In the process of drying it has slightly shrunk, so as to produce ridges and hollows of the outer crust, and this outer crust has cracked in some places, allowing portions of the pulp to ooze out—in some of them its lower dark substance, in others, its upper and lighter material. The analogy extends no farther, for there is nothing in our withered fruit to represent the oceans occupying the lower parts of the surface, or the deposits which they have laid down.

Here a most important feature demands attention. The rain, the streams, and the sea are constantly cutting down the land and depositing it in the bed of the waters. Thus weight is taken from the land, and added to the sea bed. Geological facts, such as the great thickness of the coal measures, in which we find thousands of feet of sediment, all of which must have been deposited in shallow water, and the accumulation of hundreds of feet of superficial material in deltas at the mouth of great rivers, show that the crust of the earth is so mobile as to yield downward to every pressure, however slight.[1] It may do this slowly and gradually, or by jumps from time to time; and this yielding necessarily tends to squeeze up the edges of the depressed portions into ridges, and to cause lateral movement and ejection of volcanic matter at intervals.

Keeping in view these general conclusions, let us now turn to their bearing on the origin and history of the North Atlantic.

Though the Atlantic is a deep ocean, its basin does not constitute so much a depression of the crust of the earth as a flattening of it, and this, as recent soundings have shown, with a slight ridge or elevation along its middle, and banks or terraces fringing the edges, so that its form is not so much

[1] Starkie Gardiner, *Nature*, December, 1889.

that of a basin as that of a shallow elongated plate with its middle a little raised. Its true margins are composed of portions of the over-crust folded, overlapped and crushed, as if by lateral pressure emanating from the sea itself. We cannot, for example, look at a geological map of America without perceiving that the Appalachian ridges, which intervene beween the Atlantic and the St. Lawrence valley, have been driven bodily back by a force acting from the east, and that they have resisted this pressure only where, as in the Gulf of St. Lawrence and the Catskill region of New York, they have been protected by outlying masses of very old rocks, as, for example, by that of the island of Newfoundland and that of the Adirondack Mountains. The admirable work begun by my friend and fellow-student, Professor James Nicol, followed up by Professor Lapworth, and now, after long controversy, fully confirmed by the recent observations of the Geological Survey of Scotland, has shown the most intense action of the same kind on the east side of the ocean in the Scottish highlands; and the more widely distributed Eozoic and other old rocks of Scandinavia may be appealed to in further evidence of this.[1]

If we now inquire as to the cause of the Atlantic depression, we must go back to the time when the areas occupied by the Atlantic and its bounding coasts were parts of the shoreless sea in which the earliest gneisses or stratified granites of the Laurentian age were being laid down in vastly extended beds. These ancient crystalline rocks have been the subject of much discussion and controversy, to which reference has been made in a previous chapter.

It will be observed, in regard to these theories, that they do

[1] Address to Geological Section, Brit. Assoc., by Prof. Judd, Aberdeen Meeting, 1885. According to Rogers, the crumpling of the Appalachians has reduced a breadth of 158 miles to about 60. Geikie, Address, Geological Society, 1891–2.

not suppose that the old gneiss is an ordinary sediment, but that all regard it as formed in exceptional circumstances, these circumstances being the absence of land and of subaërial decay of rock, and the presence wholly or principally of the material of the upper surface of the recently hardened crust. This being granted, the question arises, Ought we not to combine the several theories as to the origin of gneiss, and to believe that the cooling crust has hardened in successive layers from without inward; that at the same time fissures were locally discharging igneous matter to the surface; that matter held in supension in the ocean and matter held in solution by heated waters rising from beneath the outer crust were mingling their materials in the deposits of the primitive ocean?[1] It would seem that the combination of all these agencies may safely be evoked as causes of the pre-Atlantic deposits. This is the eclectic position I have maintained in a previous chapter, and which I hold to be in every way the most probable.

Let us suppose, then, the floor of old ocean covered with a flat pavement of gneiss, or of that material which is now gneiss, the next question is, How and when did this original bed become converted into sea and land? Here we have some things certain, others most debateable. That the cooling mass, especially if it was sending out volumes of softened rocky material, either in the form of volcanic ejections or in that of matter dissolved in heated water, and piling this on the surface, must soon become too small for its shell, is apparent; but when and where would the collapse, crushing and wrinkling inevitable from this cause begin? The date is indicated by the lines of old mountain chains which traverse the Laurentian districts; but the reason why is less apparent. The more or less unequal cooling, hardening and conductive power of the outer crust we may readily assume. The driftage unequally of water-borne detritus to the south-west by the

[1] Hunt, *Transactions Royal Society of Canada*, 1885.

bottom currents of the sea is another cause, and, as we shall soon see, most effective. Still another is the greater cooling and hardening of the crust in the polar regions, and the tendency to collapse of the equatorial protuberance from the slackening of the earth's rotation. Besides these, the internal tides of the earth's substance at the times of solstice would exert an oblique pulling force on the crust, which might tend to crack it along diagonal lines. From whichever of these causes, or the combination of the whole, we know that, within the Laurentian time, folded portions of the earth's crust began to rise above the general surface, in broad belts running from north-east to south-west, and from north-west to south-east, where the older mountains of Eastern America and Western Europe now stand, and that the subsidence of the oceanic areas, allowed by this crumpling of the crust, permitted other areas on both sides of the Atlantic to form limited table-lands. This was the commencement of a process repeated again and again in subsequent times, and which began in the middle Laurentian, when for the first time we find beds of quartzite, limestone, and iron ore, and graphite beds, indicating that there was already land and water, and that the sea, and perhaps the land, swarmed with forms of animal and plant life, unknown, for the most part, now. Independently of the questions as to the animal nature of Eozoon, I hold that we know, as certainly as we can know anything inferentially, the existence of these primitive forms of life. If I were to conjecture what were these early forms of plant and animal life, still unknown to us by actual specimens, I would suppose that, just as in the Palæozoic, the acrogens culminated in gigantic and complex forest trees, so in the Laurentian, the algæ, the lichens, and the mosses grew to dimensions and assumed complexity of structure unexampled in later times, and that, in the sea, the humbler forms of Protozoa and Sea Mosses were the dominant types, but in gigantic and complex forms. The land of this

period was probably limited, for the most part, to high latitudes, and its aspect, though more rugged and abrupt, and of greater elevation, must have been of that character which we still see in the Laurentian hills. The distribution of this ancient land is indicated by the long lines of old Laurentian rock extending from the Labrador coast and the north shore of the St. Lawrence, and along the eastern slopes of the Appalachians in America, and the like rocks of the Hebrides, the Western Highlands, and the Scandinavian mountains. A small but interesting remnant is that in the Malvern Hills, so well described by Holl. It will be well to note here, and to fix on our minds, that these ancient ridges of Eastern America and Western Europe have been greatly denuded and wasted since Laurentian times, and that it is along their eastern sides that the greatest sedimentary accumulations have been deposited.

From this time dates the introduction of that dominance of existing causes which forms the basis of uniformitarianism in geology, and which had to go on with various and great modifications of detail, through the successive stages of the geological history, till the land and water of the northern hemisphere attained to their present complex structure.

So soon as we have a circumpolar belt or patches of Eozoic[1] land and ridges running southward from it, we enter on new and more complicated methods of growth of the continents and seas. Portions of the oldest crystalline rocks, raised out of the protecting water, were now eroded by atmospheric agents, and especially by the carbonic acid, then existing in the atmosphere perhaps more abundantly than at present, under whose influence the hardest of the gneissic rocks gradually decay. The arctic lands were subjected, in addition, to the powerful mechanical force of frost and thaw. Thus every shower of rain and every swollen stream would carry into the

[1] Or Archæan, or pre-Cambrian, if these terms are preferred.

sea the products of the waste of land, sorting them into fine clays and coarser sands; and the cold currents which cling to the ocean bottom, now determined in their courses, not merely by the earth's rotation, but also by the lines of folding on both sides of the Atlantic, would carry south-westward, and pile up in marginal banks of great thickness the *débris* produced from the rapid waste of the land already existing in the Arctic regions. The Atlantic, opening widely to the north, and having large rivers pouring into it, was, especially, the ocean characterised, as time advanced, by the prevalence of these phenomena. Thus, throughout the geological history it has happened that, while the middle of the Atlantic has received merely organic deposits of shells of foraminifera and similar organisms, and this probably only to a small amount, its margins have had piled upon them beds of detritus of immense thickness. Professor Hall, of Albany, was the first geologist who pointed out the vast cosmic importance of these deposits, and that the mountains of both sides of the Atlantic owe their origin to these great lines of deposition, along with the fact, afterwards more fully insisted on by Rogers, that the portions of the crust which received these masses of *débris* became thereby weighted down and softened, and were more liable than other parts to lateral crushing.

Thus, in the later Eozoic and early Palæozoic times, which succeeded the first foldings of the oldest Laurentian, great ridges were thrown up, along the edges of which were beds of limestone, and on their summits and sides, thick masses of ejected igneous rocks. In the bed of the central Atlantic there are no such accumulations. It must have been a flat, or slightly ridged, plate of the ancient gneiss, hard and resisting, though perhaps with a few cracks, through which igneous matter welled up, as in Iceland and the Azores in more modern times. In this condition of things we have causes tending to perpetuate and extend the distinctions of ocean and continent,

mountain and plain, already begun; and of these we may more especially note the continued subsidence of the areas of greatest marine deposition. This has long attracted attention, and affords very convincing evidence of the connection of sedimentary deposit as a cause with the subsidence of the crust.[1]

We are indebted to a French physicist, M. Faye, for an important suggestion on this subject. It is that the sediment accumulated along the shores of the ocean presented an obstacle to radiation, and consequently to cooling of the crust, while the ocean floor, unprotected and unweighted, and constantly bathed with currents of cold water having great power of convection of heat, would be more rapidly cooled, and so would become thicker and stronger. This suggestion is complementary to the theory of Professor Hall, that the areas of greatest deposit on the margins of the ocean are necessarily those of greatest folding and consequent elevation. We have thus a hard, thick, resisting ocean bottom, which, as it settles down toward the interior, under the influence of gravity, squeezes upwards and folds and plicates all the soft sediments deposited on its edges. The Atlantic area is almost an unbroken cake of this kind. The Pacific area has cracked in many places, allowing the interior fluid matter to exude in volcanic ejections.

It may be said that all this supposes a permanent continuance of the ocean basins, whereas many geologists postulate a mid-Atlantic continent to give the thick masses of detritus found in the older formations both in Eastern America and Western Europe, and which thin off in proceeding into the

[1] Dutton in *Report of U.S. Geological Survey*, 1891. From facts stated in this report and in my "Acadian Geology," it is apparent that in the Western States and in the coalfields of Novia Scotia, shallow-water deposits have been laid down, up to thicknesses of 10,000 to 20,000 feet in connection with continuous subsidence. See also a paper by Ricketts in the *Geol. Mag.*, 1883.

interior of both continents. I prefer, as already stated, to consider these belts of sediment as the deposits of northern currents, and derived from arctic land, and that, like the great banks off the American coast at the present day, which are being built up by the present arctic current, they had little to do with any direct drainage from the adjacent shore. We need not deny, however, that such ridges of land as existed along the Atlantic margins were contributing their quota of river-borne material, just as on a still greater scale the Amazon and Mississippi are doing now, and this especially on the sides toward the present continental plateaus, though the greater part must have been derived from the wide tracts of Laurentian land within the Arctic Circle, or near to it. It is further obvious that the ordinary reasoning respecting the necessity of continental areas in the present ocean basins would actually oblige us to suppose that the whole of the oceans and continents had repeatedly changed places. This consideration opposes enormous physical difficulties to any theory of alternations of the oceanic and continental areas, except locally at their margins.

But the permanence of the Atlantic depression does not exclude the idea of successive submergences of the continental plateaus and marginal slopes, alternating with periods of elevation, when the ocean retreated from the continents and contracted its limits. In this respect the Atlantic of to-day is much smaller than it was in those times when it spread widely over the continental plains and slopes, and much larger than it has been in times of continental elevation. This leads us to the further consideration that, while the ocean beds have been sinking, other areas have been better supported, and constitute the continental plateaus; and that it has been at or near the junctions of these sinking and rising areas that the thickest deposits of detritus, the most extensive foldings, and the greatest ejections of volcanic matter have occurred. There has thus

been a permanence of the position of the continents and oceans throughout geological time, but with many oscillations of these areas, producing submergences and emergences of the land. In this way we can reconcile the vast vicissitudes of the continental areas in different geological periods with that continuity of development from north to south, and from the interiors to the margins, which is so marked a feature. We have, for this reason, to formulate another apparent geological paradox, namely, that while, in one sense, the continental and oceanic areas are permanent, in another, they have been in continual movement. Nor does this view exclude extension of the continental borders or of chains of islands beyond their present limits, at certain periods; and indeed, the general principle already stated, that subsidence of the ocean bed has produced elevation of the land, implies in earlier periods a shallower ocean and many possibilities as to volcanic islands, and low continental margins creeping out into the sea; while it is also to be noted that there are, as already stated, bordering shelves, constituting shallows in the ocean, which at certain periods have emerged as land.

We are thus compelled, as already stated, to believe in the contemporaneous existence in all geological periods, except perhaps the earliest of them, of the three distinct conditions of areas on the surface of the earth, defined in chapter second—oceanic areas of deep sea, continental plateaus and marginal shelves, and lines of plication and folding.

In the successive geological periods the continental plateaus, when submerged, owing to their vast extent of warm and shallow sea, have been the great theatres of the development of marine life and of the deposition of organic limestones, and when elevated, they have furnished the abodes of the noblest land faunas and floras. The mountain belts, especially in the north, have been the refuge and stronghold of land life in periods of submergence; and the deep ocean basins have

been the perennial abodes of pelagic and abyssal creatures and the refuge of multitudes of other marine animals and plants in times of continental elevation. These general facts are full of importance with reference to the question of the succession of formations and of life in the geological history of the earth.

So much space has been occupied with these general views, that it would be impossible to trace the history of the Atlantic in detail through the ages of the Palæozoic, Mesozoic, and Tertiary. We may, however, shortly glance at the changes of the three kinds of surface already referred to. The bed of the ocean seems to have remained, on the whole, abyssal; but there were probably periods when those shallow reaches of the Atlantic which stretch across its most northern portion, and partly separate it from the Arctic basin, presented connecting coasts or continuous chains of islands sufficient to permit animals and plants to pass over.[1] At certain periods also there were, not unlikely, groups of volcanic islands, like the Azores, in the temperate or tropical Atlantic. More especially might this be the case in that early time when it was more like the present Pacific; and the line of the great volcanic belt of the Mediterranean, the mid-Atlantic banks, the Azores and the West India Islands point to the possibility of such partial connections. These were stepping stones, so to speak, over which land organisms might cross, and some of these may be connected with the fabulous or pre-historic Atlantis.

In the Palæozoic period, the distinctions already referred to, into continental plateaus, mountain ridges, and ocean depths, were first developed, and we find, already, great masses of sediment accumulating on the seaward sides of the old Laurentian ridges, and internal deposits thinning away from these ridges over the submerged continental areas, and presenting dissimilar

[1] It would seem, from Geikie's description of the Faroe Islands, that they may be a remnant of such connecting land, dating from the Cretaceous or Eocene period.

conditions of sedimentation. It would seem also that, as Hicks has argued for Europe, and Logan and Hall for America, this Cambrian age was one of slow subsidence of the land previously elevated, accompanied with or caused by thick deposits of detritus along the borders of the subsiding shore, which was probably covered with the decomposing rock arising from long ages of subaërial waste.

In the coal formation age its characteristic swampy flats stretched in some places far into the shallower parts of the ocean.[1] In the Permian, the great plicated mountain margins were fully developed on both sides of the Atlantic. In the Jurassic, the American continent probably extended farther to the sea than at present. In the Wealden age there was much land to the west and north of Great Britain, and Professor Bonney has directed attention to the evidence of the existence of this land as far back as the Trias, while Mr. Starkie Gardiner has insisted on connecting links to the southward, as evidenced by fossil plants. So late as the Post-glacial, or early human period, large tracts, now submerged, formed portions of the continents. On the other hand, the interior plains of America and Europe were often submerged. Such submergences are indicated by the great limestones of the Palæozoic, by the chalk and its representative beds in the Cretaceous, by the Nummulitic formation in the Eocene, and lastly, by the great Pleistocene submergence, one of the most remarkable of all, one in which nearly the whole northern hemisphere participated, and which was probably separated from the present time by only a few thousands of years.[2] These submergences and ele-

[1] I have shown the evidence of this in the remnants of Carboniferous districts once more extensive on the Atlantic coast of Nova Scotia and Cape Breton ("Acadian Geology").

[2] The recent surveys of the Falls of Niagara coincide with a great many evidences to which I have elsewhere referred in proving that the Pleistocene submergence of America and Europe came to an end not more than ten

vations were not always alike on the two sides of the Atlantic. The Salina period of the Silurian, for example, and the Jurassic, show continental elevation in America not shared by Europe. The great subsidences of the Cretaceous and the Eocene were proportionally deeper and wider on the eastern continent, and this and the direction of the land being from north to south, cause more ancient forms of life to survive in America. These elevations and submergences of the plateaus alternated with the periods of mountain-making plication, which was going on at intervals, at the close of the Eozoic, at the beginning of the Cambrian, at the close of the Siluro-Cambrian, in the Permian, and in Europe and Western America in the Tertiary. The series of changes, however, affecting all these areas was of a highly complex character in detail.[1]

We may also note a fact which I have long ago insisted on,[1] the regular pulsation of the continental areas, giving us alternations in each great system of deep-sea and shallow-water beds, so that the successive groups of formations may be divided into triplets of shallow-water, deep-water, and shallow-water strata, alternating in each period. This law of succession applies more particularly to the formations of the continental plateaus, rather than to those of the ocean margins, and it shows that, intervening between the great movements of plication there were subsidences of those plateaus, or elevations of the sea bottom, which allowed the waters to spread themselves over all the inland spaces between the great folded mountain ranges of the Atlantic borders.

In referring to the ocean basins we should bear in mind that there are three of these in the northern hemisphere—the Arctic, the Pacific, and the Atlantic. De Rance has ably

thousand years ago, and was itself not of very great duration. Thus in Pleistocene times the land must have been submerged and re-elevated in a very rapid manner.

[1] "Acadian Geology."

summed up the known facts as to Arctic geology in a series of articles in *Nature*, from which it appears that this area presents from without inwards a succession of older and newer formations from the Eozoic to the Tertiary, and that its extent must have been greater in former periods than at present, while it must have enjoyed a comparatively warm climate from the Cambrian to the Pleistocene period. The relations of its deposits and fossils are closer with those of the Atlantic than with those of the Pacific, as might be anticipated from its wider opening into the former. Blandford has recently remarked on the correspondence of the marginal deposits around the Pacific and Indian oceans,[1] and Dr. Dawson informs me that this is equally marked in comparison with the west coast of America, but these marginal areas have not yet gained much on the ocean. In the North Atlantic, on the other hand, there is a wide belt of comparatively modern rocks on both sides, more especially toward the south and on the American side; but while there appears to be a perfect correspondence on both sides of the Atlantic, and around the Pacific respectively, there seems to be less parallelism between the deposits and forms of life of the two oceans, as compared with each other, and less correspondence in forms of life, especially in modern times. Still, in the earlier geological ages, as might have been anticipated from the imperfect development of the continents, the same forms of life characterise the whole ocean from Australia to Arctic America, and indicate a grand unity of Pacific and

[1] *Journal of Geological Society*, May, 1886. Blandford's statements respecting the mechanical depcsits of the close of the Palæozoic in the Indian Ocean, whether these are glacial or not, would seem to show a correspondence with the Permian conglomerates and earth movements of the Atlantic area; but since that time the Atlantic has enjoyed comparative repose. The Pacific seems to have reproduced the conditions of the Carboniferous in the Cretaceous age, and seems to have been less affected by the great changes of the Pleistocene.

Atlantic life not equalled in later times,[1] and which speaks of true contemporaneity rather than of what has been termed homotaxis or mere likeness of orders.

We may pause here for a moment to notice some of the effects of Atlantic growth on modern geography. It has given us rugged and broken shores, composed of old rocks in the north, and newer formations and softer features toward the south. It has given us marginal mountain ridges and internal plateaus on both sides of the sea. It has produced certain curious and by no means accidental correspondences of the eastern and western sides. Thus the solid basis on which the British Islands stand may be compared with Newfoundland and Labrador, the English Channel with the Gulf of St. Lawrence, the Bay of Biscay with the Bay of Maine, Spain with the projection of the American land at Cape Hatteras, the Mediterranean with the Gulf of Mexico. The special conditions of deposition and plication necessary to these results, and their bearing on the character and productions of the Atlantic basin, would require a volume for their detailed elucidation.

Thus far our discussion has been limited almost entirely to physical causes and effects. If we now turn to the life history of the Atlantic, we are met at the threshold with the question of climate, not as a thing fixed and immutable, but as changing from age to age in harmony with geographical mutations, and producing long cosmic summers and winters of alternate warmth and refrigeration.

We can scarcely doubt that the close connection of the Atlantic and Arctic oceans is one factor in those remarkable vicissitudes of climate experienced by the former, and in which the Pacific area has also shared in connection with the

[1] Daintree and Etheridge, "Queensland Geology," *Journal Geological Society*, August, 1872; R. Etheridge, Junior, "Australian Fossils," *Trans. Phys. Soc.*, Edin., 1880.

Antarctic Sea. No geölogical facts are indeed at first sight more strange and inexplicable than the changes of climate in the Atlantic area, even in comparatively modern periods. We know that in the early Tertiary temperate conditions reigned as far north as the middle of Greenland, and that in the Pleistocene the Arctic cold advanced until an almost perennial winter prevailed half way to the equator. It is no wonder that nearly every cause available in the heavens and the earth has been invoked to account for these astounding facts. I shall, I trust, be excused if, neglecting most of these theoretical views, I venture to invite attention, in connection with this question, chiefly to the old Lyellian doctrine of the modification of climate by geographical changes. Let us, at least, consider how much these are able to account for.

The ocean is a great equalizer of extremes of temperature. It does this by its great capacity for heat, and by its cooling and heating power when passing from the solid into the liquid and gaseous states, and the reverse. It also acts by its mobility, its currents serving to convey heat to great distances, or to cool the air by the movement of cold icy waters. The land, on the other hand, cools or warms rapidly, and can transmit its influence to a distance only by the winds, and the influence so transmitted is rather in the nature of a disturbing than of an equalizing cause. It follows that any change in the distribution of land and water must affect climate, more especially if it changes the character or course of the ocean currents.

Turning to the Atlantic, in this connection we perceive that its present condition is peculiar and exceptional. On the one hand it is widely open to the Arctic Sea and the influence of its cold currents, and on the other it is supplied with a heating apparatus of enormous power to give a special elevation of temperature, more particularly to its eastern coasts. The great equatorial current running across from Africa is on its northern side embayed in the Gulf of Mexico, as in a great

cauldron, and pouring through the mouth of this in the Bahama channel, forms the gulf stream, which, widening out like a fan, forms a vast expanse of warm water, from which the prevailing westerly winds of the North Atlantic waft a constant supply of heated moist air to the western coasts of Europe, giving them a much more warm and uniform climate than that which prevails in similar latitudes in Eastern America, where the cold Arctic currents hug the shore, and bring down ice from Baffin's Bay. Now all this might be differently arranged. We shall find that there were times, when the Isthmus of Panama being broken through, there was no Gulf Stream, and Norway and England were reduced to the conditions of Greenland and Labrador, and when refrigeration was still further increased by subsidence of northern lands affording freer sweep to the Arctic currents. On the other hand, there were times when the Gulf of Mexico extended much farther north than at present, and formed an additional surface of warm water to heat all the interior of America, as well as the Atlantic. Geographical changes of these kinds, have probably given us the glacial period in very recent times, and at an earlier era those warm climates which permitted temperate vegetation to flourish as far north as Greenland. These are, however, great topics, which must form the subject of other chapters.

I am old enough to remember the sensation caused by the delightful revelations of Edward Forbes respecting the zones of animal life in the sea, and the vast insight which they gave into the significance of the work on minute organisms previously done by Ehrenberg, Lonsdale and Williamson, and into the meaning of fossil remains. A little later the soundings for the Atlantic cable revealed the chalky foraminiferal ooze of the abyssal ocean. Still more recently, the wealth of facts disclosed by the *Challenger* voyage, which naturalists have scarcely yet had time to digest, have opened up to us new worlds of deep-sea life.

The bed of the deep Atlantic is covered, for the most part, by a mud or ooze, largely made up of the *débris* of foraminifera and other minute organisms mixed with fine clay. In the North Atlantic the Norwegian naturalists call this the Biloculina mud. Farther south, the *Challenger* naturalists speak of it as Globigerina ooze. In point of fact it contains different species of foraminiferal shells, Globigerina and Orbulina being in some localities dominant, and in others, other species; and these changes are more apparent in the shallower portions of the ocean.

On the other hand, there are means for disseminating coarse material over parts of the ocean beds. There are, in the line of the Arctic current, on the American coast, great sand banks, and off the coast of Norway, sand constitutes a considerable part of the bottom material. Soundings and dredgings off Great Britain, and also off the American coast, have shown that fragments of stone referable to Arctic lands are abundantly strewn over the bottom, along certain lines, and the Antarctic continent, otherwise almost unknown, makes its presence felt to the dredge by the abundant masses of crystalline rock drifted far from it to the north. These are not altogether new discoveries. I had inferred, many years ago, from stones taken up by the hooks of fishermen on the banks of Newfoundland, that rocky material from the north is dropped on these banks by the heavy ice which drifts over them every spring, that these are glaciated, and that after they fall to the bottom sand is drifted over them with sufficient velocity to polish the stones, and to erode the shelly coverings of Arctic animals attached to them.[1] If, then, the Atlantic basin were upheaved into land, we should see beds of sand, gravel and boulders with clay flats and layers of marl and limestone. According to the *Challenger* reports, in the Antarctic seas S. of 64° there is blue mud, with fragments of rock, in depths

[1] "Notes on Post-Pliocine of Canada," 1872.

of 1,200 to 2,000 fathoms. The stones, some of them glaciated, were granite, diorite, amphibolite, mica schist, gneiss and quartzite. This deposit ceases and gives place to Globigerina ooze and red clay at 46° to 47° S., but even farther north there is sometimes as much as 49 per cent. of crystalline sand. In the Labrador current a block of syenite, weighing 400 lbs., was taken up from 1,340 fathoms, and in the Arctic current, 100 miles from land, was a stony deposit, some stones being glaciated. Among these were smoky quartz, quartzite, limestone, dolomite, mica schist, and serpentine; also particles of monoclinic and triclinic felspar, hornblende, augite, magnetite, mica and glauconite, the latter, no doubt, formed in the sea bottom, the others drifted from Eozoic and Palæozoic formations to the north.[1]

A remarkable fact in this connection is that the great depths of the sea are as impassable to the majority of marine animals as the land itself. According to Murray, while twelve of the *Challenger's* dredgings, taken in depths greater than 2,000 fathoms, gave 92 species, mostly new to science, a similar number of dredgings in shallower water near the land, give no less than 1,000 species. Hence arises another apparent paradox relating to the distribution of organic beings. While at first sight it might seem that the chances of wide distribution are exceptionally great for marine species, this is not so. Except in the case of those which enjoy a period of free locomotion when young, or are floating and pelagic, the deep ocean sets bounds to their migrations. On the other hand, the spores of cryptogamic plants may be carried for vast distances by the wind, and the growth of volcanic islands may effect connections which, though only temporary, may afford opportunity for land animals and plants to pass over.

With reference to the transmission of living beings across the Atlantic, we have before us the remarkable fact that from

[1] *General Report, "Challenger" Expedition.*

the Cambrian age onwards there were, on the two sides of the ocean, many species of invertebrate animals which were either identical or so closely allied as to be possibly varietal forms, indicating probably the shallowness of the ocean in these periods. In like manner, the early plants of the Upper Silurian, Devonian, and Carboniferous present many identical species; but this identity is less marked in more modern times. Even in the latter, however, there are remarkable connections between the floras of oceanic islands and the continents. Thus the Bermudas, altogether recent islands, have been stocked by the agency chiefly of the ocean currents and of birds, with nearly 150 species of continental plants; and the facts collected by Helmsley as to the present facilities of transmission, along with the evidence afforded by older oceanic islands which have been receiving animal and vegetable colonists for longer periods, go far to show that, time being given, the sea actually affords facilities for the migration of the inhabitants of the land, comparable with those of continuous continents.

In so far as plants are concerned, it is to be observed that the early forests were largely composed of cryptogamous plants, and the spores of these in modern times have proved capable of transmission from great distances. In considering this, we cannot fail to conclude, that the union of simple cryptogamous fructification with arboreal stems of high complexity, so well illustrated by Dr. Williamson, had a direct relation to the necessity for a rapid and wide distribution of these ancient trees. It seems also certain that some spores, as, for example, those of the Rhizocarps,[1] a type of vegetation abundant in the Palæozoic, and certain kinds of seeds, as those named *Æthoetesta* and *Pachytheca*, were fitted for flotation. Further, the periods of Arctic warmth permitted the passage around

[1] See paper by the author on Palæozoic Rhizocarps, *Chicago Trans.*, 1886.

the northern belt of many temperate species of plants, just as now happens with the Arctic flora; and when these were displaced by colder periods, they marched southward along both sides of the sea on the mountain chains.

The same remark applies to northern forms of marine invertebrates, which are much more widely distributed in longitude than those farther south. The late Mr. Gywn Jeffreys, in one of his latest communications on this subject, stated that 54 per cent. of the shallow-water mollusks of New England and Canada are also European, and of the deep-sea forms, 30 out of 35; these last, of course, enjoying greater facilities for migration than those which have to travel slowly along the shallows of the coast in order to cross the ocean and settle themselves on both sides. Many of these animals, like the common mussel and sand clam, are old settlers which came over in the Pleistocene period, or even earlier. Others, like the common periwinkle, seem to have been slowly extending themselves in modern times, perhaps even by the agency of man. The older immigrants may possibly have taken advantage of lines of coast now submerged, or of warm periods, when they could creep round the Arctic shores. Mr. Herbert Carpenter and other naturalists employed on the *Challenger* collections have made similar statements respecting other marine invertebrates, as, for instance, the Echinoderms, of which the deep-sea crinoids present many common species, and my own collections prove that many of the shallow-water forms are common. Dall and Whiteaves[1] have shown that some mollusks and Echinoderms are common even to the Atlantic and Pacific coasts of North America; a remarkable fact, testifying at once to the fixity of these species and to the manner in which they have been able to take advantage of geographical changes. Some of the species of whelks common to the Gulf of St. Lawrence and the Pacific are animals which have no special

[1] Dall, *Report on Alaska*; Whiteaves, *Trans. R. S. C.*

locomotive powers, even when young, but they are northern forms not proceeding far south, so that they may have passed through the Arctic seas. In this connection it is well to remark that many species of animals have powers of locomotion in youth which they lose when adult, and that others may have special means of transit. I once found at Gaspé a specimen of the Pacific species of Coronula, or whale-barnacle, the *C. reginæ* of Darwin, attached to a whale taken in the Gulf of St. Lawrence, and which had possibly succeeded in making that passage around the north of America which so many navigators have essayed in vain.[1]

But it is to be remarked that while many plants and marine invertebrates are common to the two sides of the Atlantic, it is different with land animals, and especially vertebrates. I do not know that any palæozoic insects or land snails or millipedes of Europe and America are specifically identical, and of the numerous species of batrachians of the Carboniferous and reptiles of the Mesozoic, all seem to be distinct on the two sides. The same appears to be the case with the Tertiary mammals, until in the later stages of that great period we find such genera as the horse, the camel, and the elephant appearing on the two sides of the Atlantic ; but even then the species seem different, except in the case of a few northern forms.

Some of the longer-lived mollusks of the Atlantic furnish suggestions which remarkably illustrate the biological aspect of these questions. Our familiar friend the oyster is one of these. The first-known oysters appear in the Carboniferous in Belgium and in the United States of America. In the Carboniferous and Permian they are few and small, and they do not culminate till the Cretaceous, in which there are no less than ninety-one so-called species in America alone ; but some of the largest known species are found in the Eocene. The oyster, though

[1] I am informed, however, that the Coronula is found also in the Biscayan whales.

an inhabitant of shallow water, and very limitedly locomotive when young, has survived all the changes since the Carboniferous age, and has spread itself over the whole northern hemisphere,[1] though a warm water rather than Arctic type.

I have collected fossil oysters in the Cretaceous clays of the coulées of Western Canada, in the Lias shales of England, in the Eocene and the Cretaceous beds of the Alps, of Egypt, of the Red Sea coast, of Judea, and the heights of Lebanon. Everywhere and in all formations they present forms which are so variable and yet so similar that one might suppose all the so-called species to be mere varieties. Did the oyster originate separately on the two sides of the Atlantic, or did it cross over so promptly that its appearance seems to be identical on the two sides? Are all the oysters of a common ancestry, or did the causes, whatever they were, which introduced the oyster in the Carboniferous act over again in later periods? Who can tell? This is one of the cases where causation and development—the two scientific factors which constitute the basis of what is called evolution—cannot easily be isolated. I would recommend to those biologists who discuss these questions to devote themselves to the oyster. This familiar mollusk has successfully pursued its course, and has overcome all its enemies, from the flat-toothed selachians of the Carboniferous to the oyster dredges of the present day, has varied almost indefinitely, and yet has continued to be an oyster, unless, indeed, it may at certain portions of its career have temporarily assumed the guise of a Gryphæa or an Exogyra. The history of such an animal deserves to be traced with care, and much curious information respecting it will be found in the report which I have cited in the note.

But in these respects the oyster is merely an example of many forms. Similar considerations apply to all those Pliocene and Pleistocene mollusks which are found in the raised sea

[1] White, *Report U. S. Geol. Survey*, 1882–83.

bottoms of Norway and Scotland, on the top of Moel Tryfaen, in Wales, and at similar great heights on the hills of America, many of which can be traced back to early Tertiary times, and can be found to have extended themselves over all the seas of the northern hemisphere. They apply in like manner to the ferns, the conifers, and the broad-leaved trees, many of which we can now trace without specific change to the Eocene and Cretaceous. They all show that the forms of living things are more stable than the lands and seas in which they live. If we were to adopt some of the modern ideas of evolution, we might cut the Gordian knot by supposing that, as like causes produce like effects, these types of life have originated more than once in geological time, and need not be genetically connected with each other. But while evolutionists repudiate such an application of their doctrine, however natural and rational, it would seem that nature still more strongly repudiates it, and will not allow us to assume more than one origin for one species. Thus the great question of geographical distribution remains in all its force; and, by still another of our geological paradoxes, mountains become ephemeral things in comparison with the delicate herbage which covers them, and seas are in their present extent but of yesterday, when compared with the minute and feeble organisms that creep on their sands or swim in their waters.

The question remains: Has the Atlantic achieved its destiny and finished its course, or are there other changes in store for it in the future? The earth's crust is now thicker and stronger than ever before, and its great ribs of crushed and folded rock are more firm and rigid than in any previous period. The stupendous volcanic phenomena manifested in Mesozoic and early Tertiary times along the borders of the Atlantic have apparently died out. These facts are in so far guarantees of permanence. On the other hand, it is known that movements of elevation, along with local depression, are in progress

in the Arctic regions, and a great weight of new sediment is being deposited along the borders of the Atlantic, especially on its western side ; and this is not improbably connected with the earthquake shocks and slight movements of depression which have occurred in North America. It is possible that these slight and secular movements may go on uninterruptedly, or with occasional paroxysmal disturbances, until considerable changes are produced.

It is possible, on the other hand, that after the long period of quiescence which has elapsed, there may be a new settlement of the ocean bed, accompanied with foldings of the crust, especially on the western side of the Atlantic, and possibly with renewed volcanic activity on its eastern margin. In either case, a long time relatively to our limited human chronology may intervene before the occurrence of any marked change. On the whole, the experience of the past would lead us to expect movements and eruptive discharges in the Pacific rather than in the Atlantic area. It is therefore not unlikely that the Atlantic may remain undisturbed, unless secondarily and indirectly, until after the Pacific area shall have attained to a greater degree of quiescence than at present. But this subject is one too much involved in uncertainty to warrant us in following it farther.

In the meantime the Atlantic is to us a practically permanent ocean, varying only in its tides, its currents, and its winds, which science has already reduced to definite laws, so that we can use if we cannot regulate them. It is ours to take advantage of this precious time of quietude, and to extend the blessings of science and of our Christian civilisation from shore to shore, until there shall be no more sea, not in the sense of that final drying-up of old ocean to which some physicists look forward, but in the higher sense of its ceasing to be the emblem of unrest and disturbance, and the cause of isolation.

I must now close this chapter with a short statement of some

general truths which I have had in view in directing attention to the geological development of the Atlantic. We cannot, I think, consider the topics to which I have referred without perceiving that the history of ocean and continent is an example of progressive design, quite as much as that of living beings. Nor can we fail to see that, while in some important directions we have penetrated the great secret of nature, in reference to the general plan and structure of the earth and its waters, and the changes through which they have passed, we have still very much to learn, and perhaps quite as much to unlearn, and that the future holds out to us and to our successors higher, grander, and clearer conceptions than those to which we have yet attained. The vastness and the might of ocean and the manner in which it cherishes the feeblest and most fragile beings, alike speak to us of Him who holds it in the hollow of His hand, and gave to it of old its boundaries and its laws; but its teaching ascends to a higher tone when we consider its origin and history, and the manner in which it has been made to build up continents and mountain-chains, and, at the same time, to nourish and sustain the teeming life of sea and land.

REFERENCES:—Presidential Address to the British Association for the Advancement of Science, Birmingham, 1886. "Geology of Nova Scotia, New Brunswick, and Prince Edward Island." Fourth Edition, London, 1891.



THE DAWN OF LIFE.

DEDICATED TO THE MEMORY OF

SIR WILLIAM E. LOGAN,

THE UNWEARIED EXPLORER OF THE LAURENTIAN ROCKS,

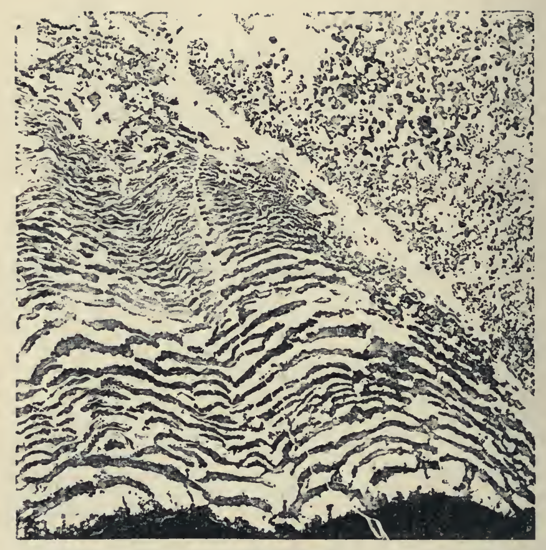
AND THE FOUNDER

OF THE

GEOLOGICAL SURVEY OF CANADA.

WHAT ARE THE OLDEST ROCKS, AND WHERE?—CONDITIONS OF THEIR FORMATION—INDICATIONS OF LIFE—WHAT ITS PROBABLE NATURE





NATURE-PRINT OF EOZOON, showing laminated, acervuline, and fragmental portions.

This is printed from an electrotype taken from an etched slab of Eozoon, and not touched with a graver except to remedy some accidental flaws in the plate. The diagonal white line marks the course of a calcite vein.

CHAPTER V.

THE DAWN OF LIFE

DO we know the first animal? Can we name it, explain its structure, and state its relations to its successors? Can we do this by inference from the succeeding types of being; and if so, do our anticipations agree with any actual reality disinterred from the earth's crust? If we could do this, either by inference or actual discovery, how strange it would be to know that we had before us even the remains of the first creature that could feel or will, and could place itself in vital relation with the great powers of inanimate nature. If we believe in a Creator, we shall feel it a solemn thing to have access to the first creature into which He breathed the breath of life. If we hold that all things have been evolved from collision of dead forces, then the first molecules of matter which took upon themselves the responsibility of living, and, aiming at the enjoyment of happiness, subjected themselves to the dread alternatives of pain and mortality, must surely evoke from us that filial reverence which we owe to the authors of our own being; if they do not involuntarily draw forth even a superstitious adoration. The veneration of the old Egyptian for his sacred animals would be a comparatively reasonable idolatry, if we could imagine any of these animals to have been the first that emerged from the domain of dead matter, and the first link in a reproductive chain of being that produced all the population of the world. Independently of any such hypotheses, all students of nature must regard with surpassing

interest the first bright streaks of light that break on the long reign of primeval night and death, and presage the busy day of teeming animal existence.

No wonder, then, that geologists have long and earnestly groped in the rocky archives of the earth in search of some record of this patriarch of the animal kingdom. But after long and patient research there still remained a large residuum of the oldest rocks destitute of all traces of living beings, and designated by the hopeless name "Azoic,"—the formations destitute of remains of life, the stony records of a lifeless world. So the matter remained till the Laurentian rocks of Canada, lying at the base of these old Azoic formations, afforded forms believed to be of organic origin. The discovery was hailed with enthusiasm by those who had been prepared by previous study to receive it. It was regarded with feeble and not very intelligent faith by many more, and was met with half-concealed or open scepticism by others. It produced a copious crop of descriptive and controversial literature, but for the most part technical, and confined to scientific transactions and periodicals, read by very few except specialists. Thus, few even of geological and biological students have clear ideas of the real nature and mode of occurrence of these ancient organisms, if organisms they are, and of their relations to better known forms of life; while the crudest and most inaccurate ideas have been current in lectures and popular books, and even in text-books.

This state of things has long ceased to be desirable in the interests of science, since the settlement of the questions raised is in the highest degree important to the history of life. We cannot, it is true, affirm that Eozoön is in reality the long-sought prototype of animal existence; but it was for us, at least until recently, the last organic foothold, on which we can poise ourselves, that we may look back into the abyss of the infinite past, and forward to the long and varied progress of life in

geological time. Now, however, we have announcements to be referred to in the sequel of other organisms discovered in the so-called Archæan rocks; and it is not improbable that these will rapidly increase. The discussion of its claims has also raised questions and introduced new points, certain, if properly entered into, to be fruitful of interesting and valuable thought, and to form a good introduction to the history of life in connection with geology.

As we descend in depth and time into the earth's crust, after passing through nearly all the vast series of strata constituting the monuments of geological history, we at length reach the Eozoic or Laurentian rocks,[1] deepest and oldest of all the formations known to the geologist, and more thoroughly altered or metamorphosed by heat and heated moisture than any others. These rocks, at one time known as Azoic, being supposed destitute of all remains of living things, but now more properly Eozoic, are those in which the first bright streaks of the dawn of life make their appearance.

The name Laurentian, given originally to the Canadian development of these rocks by Sir William Logan, but now applied to them throughout the world, is derived from a range of hills lying north of the St. Lawrence valley, which the old French geographers named the Laurentides. In these hills the harder rocks of this old formation rise to considerable heights, and form the highlands separating the St. Lawrence valley from the great plain fronting on Hudson's Bay and the Arctic Sea. At first sight it may seem strange that rocks so ancient should anywhere appear at the surface, especially on the tops of hills; but this is a necessary result of the mode of formation of our continents. The most ancient sediments deposited in the sea were those first elevated into land, and first altered and hardened. Upheaved in the folding of the earth's crust into high and rugged ridges, they have either re-

[1] Otherwise named "Archæan."

mained uncovered with newer sediments, or have had such as were deposited on them washed away; and being of a hard and resisting nature, they have remained comparatively unworn when rocks much more modern have been swept off by denuding agencies.[1]

But the exposure of the old Laurentian skeleton of mother earth is not confined to the Laurentide Hills, though these have given the formation its name. The same ancient rocks appear in the Adirondack mountains of New York, and in the patches which at lower levels protrude from beneath the newer formations along the American coast from Newfoundland to Maryland. The older gneisses of Norway, Sweden, and the Hebrides, of Bavaria and Bohemia, of Egypt, Abyssinia and Arabia, belong to the same age, and it is not unlikely that similar rocks in many other parts of the old continent will be found to be of as great antiquity. In no part of the world, however, are the Laurentian rocks more extensively distributed or better known than in Canada; and to this as the grandest and most instructive development of them we may more especially devote our attention.

The Laurentian rocks, associated with another series only a little younger, the Huronian, form a great belt of broken and hilly country, extending from Labrador across the north of Canada to Lake Superior, and thence bending northward to the Arctic Sea. Everywhere on the lower St. Lawrence they appear as ranges of billowy rounded ridges on the north side of the river, and as viewed from the water or the southern shore, especially when sunset deepens their tints to blue and violet, they present a grand and massive appearance, which, in the eye of the geologist, who knows that they have endured the battles and the storms of time longer than any other moun-

[1] This implies the permanence of continents in their main features, a doctrine the writer has maintained for thirty years, and which is discussed elsewhere.

tains, invests them with the dignity which their mere elevation would fail to give. (Fig. 1.) In the isolated mass of the Adirondacks, south of the Canadian frontier, they rise to a still greater elevation, and form an imposing mountain group, almost equal in height to their somewhat more modern rivals, the White Mountains, which face them on the opposite side of Lake Champlain.

The grandeur of the old Laurentian ranges is, however, best displayed where they have been cut across by the great transverse gorge of the Saguenay, and where the magnificent precipices, known as Capes Trinity and Eternity, look down from their elevation of 1,500 feet on the fiord, which at their feet is more than 100 fathoms deep. The name Eternity applied to such a mass is geologically scarcely a misnomer, for it dates back to the very dawn of geological time, and is of hoar antiquity in comparison with such upstart ranges as the Andes and the Alps. (See Frontispiece.)

On a nearer acquaintance, the Laurentian country appears as a broken and hilly upland and highland district, clad in its pristine state with magnificent forests, but affording few attractions to the agriculturist, except in the valleys, which follow the lines of its softer beds, while it is a favourite region for the angler, the hunter, and the lumberman. Many of the Laurentian townships of Canada are, however, already extensively settled, and the traveller may pass through a succession of more or less cultivated valleys, bounded by rocks or wooded hills and crags, and diversified by running streams and romantic lakes and ponds, constituting a country always picturesque and often beautiful, and rearing a strong and hardy population. To the geologist it presents in the main immensely thick beds of gneiss, bedded diorite and quartzite, and similar crystalline rocks, contorted in the most remarkable manner, so that if they could be flattened out they would serve as a skin much too large for mother earth in her present state, so much has



Fig. 1.—Laurentian Hills opposite Kamouraska, Lower St. Lawrence. The Islands in front are Cambro-Silurian.

she shrunk and wrinkled since those youthful days when the Laurentian rocks were her outer covering.

I cannot describe such rocks, but their names, as given in the section, Fig. 2, will tell something to those who have any knowledge of the older crystalline materials of the earth's crust. To those who have not, I would advise a visit to some cliff on the lower St. Lawrence, or the Hebridean coasts, or the shore of Norway, where the old hard crystalline and gnarled beds present their sharp edges to the ever raging sea, and show their endless alternations of various kinds and colours of strata, often diversified with veins and nests of crystalline minerals. He who has seen and studied such a section of Laurentian rock cannot forget it.

The elaborate stratigraphical work of Sir William Logan has proved that these old crystalline rocks are bedded or stratified, and that they must have been deposited in succession by some process of aqueous action. They have, however, through geological ages of vast duration been subjected to pressure and chemical action, which have, as stated in a previous chapter, much modified their structure, while it is also certain that they must have differed originally from the sands, clays and other materials laid down in the sea in later times.

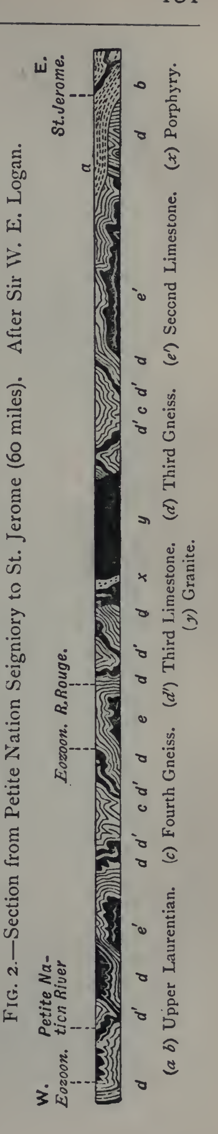


FIG. 2.—Section from Petite Nation Seigniory to St. Jerome (60 miles). After Sir W. E. Logan.

(a b) Upper Laurentian. (c) Fourth Gneiss. (d') Third Limestone. (d) Third Gneiss. (e') Second Limestone. (x) Porphyry. (y) Granite.

It is interesting to notice here that the Laurentian rocks thus interpreted show that the oldest known portions of our continents were formed in the waters. They are oceanic sediments deposited perhaps when there was no dry land, or very little, and that little unknown to us, except in so far as its *débris* may have entered into the composition of the Laurentian rocks themselves. Thus the earliest condition of the earth known to the geologist is one in which old ocean was already dominant on its surface; and any previous condition when the surface was heated, and the water constituted an abyss of vapours enveloping its surface, or any still earlier condition in which the earth was gaseous or vaporous, is a matter of mere inference, not of actual observation. The formless and void chaos is a deduction of chemical and physical principles, not a fact observed by the geologist. Still we know, from the great dykes and masses of igneous or molten rock which traverse the Laurentian beds, that even at that early period there were deep-seated fires beneath the crust; and it is quite possible that volcanic agencies then manifested themselves, not only with quite as great intensity, but also in the same manner, as at subsequent times. It is thus not unlikely that much of the land undergoing waste in the earlier Laurentian time was of the same nature with recent volcanic ejections, and that it formed groups of islands in an otherwise boundless ocean.

However this may be, the distribution and extent of these pre-Laurentian lands is, and probably ever must be, unknown to us; for it was only after the Laurentian rocks had been deposited, and after the shrinkage and deformation of the earth's crust in subsequent times had bent and contorted them, that the foundations of the continents were laid. The rude sketch map of America given in Fig. 3 will show this, and will also show that the old Laurentian mountains mark out the future form of the American continent.

Some subsequent writers have, it is true, treated with disbelief Logan's great discoveries; but no competent geologist who has traced the regularly bedded limestones and other rocks of his original fields of investigation could continue to doubt. On this subject I may quote from my friend Dr. Bonney, one of the most judicious of the builders who undertake hypothetically to lay the foundation stones of the earth's



FIG. 3.—The Laurentian Nucleus of the American Continent, after Dana.

crust for our enlightenment in these later days. In an address delivered at the Bath meeting of the British Association he says:—

"The first deposits on the solidified crust of the earth would obviously be igneous. As water condensed from the atmosphere on the cooling surface, aqueous waste or condensation would begin, and stratified deposits in the ocean would become

possible in addition to detrital volcanic material. But at that time the crust itself, and even later stratified deposits would often be kept for a considerable period at a high temperature. Thus, not only rocks of igneous origin (including volcanic ashes) would predominate in the lowest foundation stones, but also secondary changes would occur more readily, and even the sediments or precipitates might be greatly modified. As time went on, true sediments would predominate over volcanic materials, and these would be less and less affected by chemical changes, and would more and more retain their original character. Thus we should expect that as we retraced the earth's course through 'the corridor of time' we should arrive at rocks which, though crystalline in structure, were evidently in great part sedimentary in origin, and should behind them find rocks of more coarsely crystalline texture and more dubious character, which, however, probably were in part of a like origin, and should at last reach coarsely crystalline rocks, in which, while occasional sediments would be possible, the majority were originally igneous, though modified at a very early period of their history. This corresponds with what we find in nature, when we apply, cautiously and tentatively, the principles of interpretation which guide us in stratigraphical geology."[1]

This expresses very well the general result of the patient stratigraphical and chemical labours of Logan and Sterry Hunt, as applied to the vast areas of old crystalline stratified rocks in Canada, and which I have had abundant opportunities to verify on the ground. Under the undoubted Cambrian beds of Canada lies the Huronian, a formation largely of hardened sands, clays and gravels, now forming sandstones, slates, and conglomerates, but with great beds of igneous or volcanic rock, and hardened and altered ash beds. Under

[1] "The Foundation Stones of the Earth's Crust," 1888. The extract is slightly condensed.

this, in the upper portion of the Laurentian, we have regularly bedded rocks, quartzites, limestones, and quartzose, and graphitic and ferruginous gneisses, evidently altered aqueous sediments; but intermixed with other rocks, as diorites and hornblendic gneisses, which are plainly of different origin. Lastly, on the bottom of all, we have nothing but coarse crystalline gneiss, representing perhaps the earliest crust of a cooling globe. Broadly, and without entering into details or theoretical views as to the precise causes of formation and alteration of these rocks, this is the structure of the Archæan or Eozoic system in Canada; and it corresponds with that of the basement or foundation stones of our continents in every country that I have been able to visit, or of which I have trustworthy accounts.

In the lower or fundamental gneiss, and in the igneous beds which succeed it, we need not look for any indications of living beings; but so soon as the sea began to deposit sand, mud, limestone, iron ore, carbon, there would be nothing to exclude the presence of some forms of marine life; while, as land must have already existed, there would be a possibility of life on it. This, therefore, we may begin to look for so soon as we ascend to those beds of the Laurentian in which limestone, iron ore, and quartzite appear; and it is precisely at this point in the Laurentian of Canada that indications of life are supposed to have been found. Certain it is that if we cannot find some sign of life in the Laurentian or Huronian, we shall have to face as the beginnings of life the swarms of marine creatures that appear all over the globe at once, in the early Cambrian age.

Is it likely, then, that such rocks should afford any traces of living beings, even if any such existed when they were formed? Geologists who had traced organic remains back to the lowest Cambrian might hope for such remains, even in the Laurentian; but they long looked in vain for their actual discovery.

Still, as astronomers have suspected the existence of unknown planets from observing perturbations not accounted for, and as voyagers have suspected the approach to unknown regions by the appearance of floating wood or stray land birds, anticipations of such discoveries have been entertained and expressed from time to time. Lyell, Dana, and Dr. Sterry Hunt more especially have committed themselves to such speculations. The reasons assigned may be stated thus :—

Assuming the Laurentian rocks to be altered sediments, they must, from their great extent, have been deposited in the ocean; and if there had been no living creatures in the waters, we have no reason to believe that they would have consisted of anything more than such sandy and muddy *débris* as may be washed away from wasting rocks originally of igneous origin. But the Laurentian beds contain other materials than these. No formations of any geological age include thicker or more extensive limestones. One of the beds measured by the officers of the Geological Survey is stated to be 1,500 feet in thickness, another is 1,250 feet thick, and a third, 750 feet; making an aggregate of 3,500 feet.[1] These beds may be traced, with more or less interruption, for hundreds of miles. Whatever the origin of such limestones, it is plain that they indicate causes equal in extent, and comparable in power and duration, with those which have produced the greatest limestones of the later geological periods. Now, in later formations, limestone is usually an organic rock, accumulated by the slow gathering from the sea-water, or its plants, of calcareous matter, by corals, foraminifera, or shell fish, and the deposition of their skeletons, either entire or in fragments, in the sea bottom. The most friable chalk and the most crystalline limestones have alike been formed in this way. We know of no reason why it should be different in the Laurentian period. When,

[1] Logan : "Geology of Canada," p. 45.

therefore, we find great and conformable beds of limestone, such as those described by Sir William Logan in the Laurentian of Canada, we naturally imagine a quiet sea bottom, in which multitudes of animals of humble organization were accumulating limestone in their hard parts, and depositing this in gradually increasing thickness from age to age. Any attempts to account otherwise for these thick and greatly extended beds, regularly interstratified with other deposits, have so far been failures, and have arisen either from a want of comprehension of the nature and magnitude of the appearances to be explained, or from the error of mistaking the true bedded limestones for veins of calcareous spar.

The Laurentian rocks contain great quantities of carbon, in the form of graphite or plumbago. This does not occur wholly, or even principally, in veins or fissures, but in the substance of the limestone and gneiss, and in regular layers. So abundant is it, that I have estimated the amount of carbon in one division of the Lower Laurentian of the Ottawa district at an aggregate thickness of not less than twenty to thirty feet, an amount comparable with that in the true coal formation itself. Now we know of no agency existing in present or in past geological time capable of deoxidizing carbonic acid, and fixing its carbon as an ingredient in permanent rocks, except vegetable life. Unless, therefore, we suppose that there existed in the Laurentian age a vast abundance of vegetation, either in the sea or on the land, we have no means of explaining the Laurentian graphite.

The Laurentian formation contains great beds of oxide of iron, sometimes seventy feet in thickness. Here, again, we have an evidence of organic action; for it is the deoxidizing power of vegetable matter which has in all the later formations been the efficient cause in producing bedded deposits of iron. This is the case in modern bog and lake ores, in the clay ironstones of the coal measures, and apparently, also, in the great

ore beds of the Silurian rocks. May not similar causes have been at work in the Laurentian period?

Any one of these reasons might, in itself, be held insufficient to prove so great and, at first sight, unlikely a conclusion as that of the existence of abundant animal and vegetable life in the Laurentian; but the concurrence of the whole in a series of deposits unquestionably marine, forms a chain of evidence so powerful that it might command belief even if no fragment of any organic and living form or structure had ever been recognised in these ancient rocks.

Such was the condition of the matter until the existence of supposed organic remains was announced by Sir W. Logan, at the American Association for the Advancement of Science, in Springfield, in 1859; and we may now proceed to narrate the manner of this discovery, and how it has been followed up.

Before doing so, however, let us visit Eozoon in one of its haunts among the Laurentian Hills. One of the most noted repositories of its remains is the great Grenville band of limestone; and one of the most fruitful localities is at a place called Côte St. Pierre on this band. Leaving the train at Papineauville, we find ourselves on the Laurentian rocks, and pass over one of the great bands of gneiss for about twelve miles, to the village of St. André Avelin. On the road we see on either hand abrupt rocky ridges, partially clad with forest, and sometimes showing on their flanks the stratification of the gneiss in very distinct parallel bands, often contorted, as if the rocks, when soft, had been wrung as a washerwoman wrings clothes. Between the hills are little irregular valleys, from which the wheat and oats have just been reaped, and the tall Indian corn and yellow pumpkins are still standing in the fields. Where not cultivated, the land is covered with a rich second growth of young maples, birches, and oaks, among which still stand the stumps and tall scathed trunks of enormous pines, which constituted the original forest. Half way

we cross the Nation River, a stream nearly as large as the Tweed, flowing placidly between wooded banks, which are mirrored in its surface; but in the distance we can hear the roar of its rapids, dreaded by lumberers in their spring drivings of logs. Arrived at St. André, we find a wider valley, the indication of the change to the limestone band, and along this, with the gneiss hills still in view on either hand, and often encroaching on the road, we drive for five miles more to Côte St. Pierre. At this place the lowest depression of the valley is occupied by a little pond, and, hard by, the limestone, pro-



FIG. 4.—Attitude of Limestone at St. Pierre. (*a*) Gneiss band in the Limestone. (*b*) Limestone with Eozoon. (*c*) Diorite and Gneiss.

tected by a ridge of gneiss, rises in an abrupt wooded bank by the roadside, and a little farther forms a bare white promontory, projecting into the fields.

The limestone is here highly inclined and much contorted, and in all the excavations a thickness of about 100 feet of it may be exposed. It is white and crystalline, varying much, however, in coarseness in different bands. It is in some layers pure and white; in others it is traversed by many grey layers of gneissose and other matter, or by irregular bands and nodules of pyroxene and serpentine, and it contains subordinate beds of dolomite. In one layer only, and this but a few feet thick, does the Eozoon occur in abundance in a perfect state, though

fragments and imperfectly preserved specimens abound in other parts of the bed. It is a great mistake to suppose that it constitutes whole beds of rock in an uninterrupted mass. Its true mode of occurrence is best seen on the weathered surfaces of the rock, where the serpentinous specimens project in irregular patches of various sizes, sometimes twisted by the contortion of the beds, but often too small to suffer in this way. On such surfaces the projecting patches of the fossil exhibit laminæ of serpentine so precisely like the *Stromatoporæ* of the Silurian rocks, that any collector would pounce upon them at once as fossils. In some places these small weathered specimens can be easily chipped off from the crumbling surface of the limestone; and it is perhaps to be regretted that they have not been more extensively shown to palæontologists, with the cut slices which to many of them are so problematical. One of the original specimens, brought from the Calumet, and now in the Museum of the Geological Survey of Canada, was of this kind, and much finer specimens from Côte St. Pierre are now in that collection and in my own. A very fine example is represented on the plate facing this chapter, which is taken from an original photograph. In some of the layers are found other and more minute vesicular forms, which may be organic, and these, together with fragmental remains, as ingredients in the limestone, will be discussed in the sequel. We may merely notice here that the most abundant layer of Eozoon at this place occurs near the base of the great limestone band, and that the upper layers, in so far as seen, are less rich in it. Further, there is no necessary connection between Eozoon and the occurrence of serpentine, for there are many layers full of bands and lenticular masses of that mineral without any Eozoon except occasional fragments, while the fossil is sometimes partially mineralised with pyroxene, dolomite, or common limestone. The section in Fig. 4 will serve to show the attitude of the limestone at this place, while the more general

section, Fig. 2, page 101, taken from Sir William Logan, shows its relation to the other Laurentian rocks.

We may now notice the manner in which the specimens discovered in this and other places in the Laurentian country came to be regarded as organic.

It is a trite remark that most discoveries are made, not by one person, but by the joint exertions of many, and that they have their preparations made often long before they actually appear. For this reason I may be excused here for introducing some personal details in relation to the discovery of Eozoon, and which are indeed necessary in vindication of its claims. In this case the stable foundations were laid years before the discovery of Eozoon, by the careful surveys made by Sir William Logan and his assistants, and the chemical examination of the rocks and minerals by Dr. Sterry Hunt, which established beyond all doubt the great age and truly bedded character of the Laurentian rocks and their probable original nature, and the changes which they have experienced in the course of geological time. On the other hand, Dr. Carpenter and others in England were examining the structure of the shells of the humbler inhabitants of the modern ocean, and the manner in which the pores of their skeletons become infiltrated with mineral matter when deposited in the sea bottom. These laborious and apparently dissimilar branches of scientific inquiry were destined to be united by a series of happy discoveries, made not fortuitously but by painstaking and intelligent observers. The discovery of the most ancient fossil was thus not the chance picking up of a rare and curious specimen. It was not likely to be found in this way; and if so found, it would have remained unnoticed and of no scientific value, but for the accumulated stores of zoological and palæontological knowledge, and the surveys previously made, whereby the age and distribution of the Laurentian rocks and the chemical conditions of their deposition and metamorphism were ascertained.

The first specimens of Eozoon ever procured, in so far as known, were collected at Burgess, in Ontario, by a veteran Canadian mineralogist, Dr. Wilson, of Perth, and were sent to Sir William Logan as mineral specimens. Their chief interest at that time lay in the fact that certain laminæ of a dark green mineral present in the specimens were found, on analysis by Dr. Hunt, to be composed of a new hydrous silicate, allied to serpentine, and which he named loganite. The form of this mineral was not suspected to be of organic origin. Some years after, in 1858, other specimens, differently mineralized with the minerals serpentine and pyroxene, were found by Mr. J. McMullen, an explorer in the service of the Geological Survey, in the limestone of the Grand Calumet on the River Ottawa. These seem to have at once struck Sir W. E. Logan as resembling the Silurian fossils known as *Stromatopora*, and he showed them to Mr. Billings, the palæontologist of the survey, and to the writer, with this suggestion, confirming it with the sagacious consideration that inasmuch as the Ottawa and Burgess specimens were mineralized by different substances, yet were alike in form, there was little probability that they were merely mineral or concretionary. Mr. Billings was naturally unwilling to risk his reputation in affirming the organic nature of such specimens; and my own suggestion was that they should be sliced, and examined microscopically, and that if fossils, as they presented merely concentric laminæ and no cells, they would probably prove to be protozoa rather than corals. A few slices were accordingly made, but no definite structure could be detected. Nevertheless, Sir William Logan took some of the specimens to the meeting of the American Association at Springfield, in 1859, and exhibited them as possibly Laurentian fossils; but the announcement was evidently received with some incredulity. In 1862 they were exhibited by Sir William to some geological friends in London, but he remarks that "few seemed disposed to believe in their organic character,

Fig. 1.

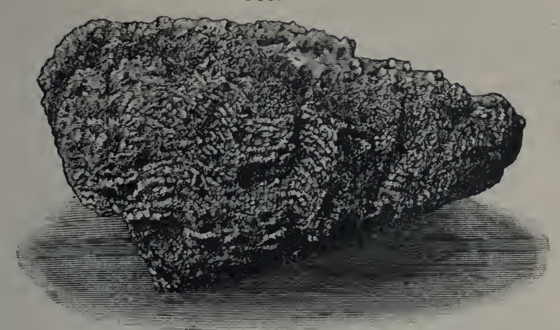


Fig. 2.



Fig. 3.



Fig. 1. Small specimen of Eozoon, weathered out, natural size, from a photograph.

Fig. 2. Canal System of Eozoon injected with serpentine (magnified).

Fig. 3. Very fine Canals and Tubuli filled with Dolomite (magnified).

(From Micro-photographs.)



with the exception of my friend, Professor Ramsay." In 1863 the general Report of the Geological Survey, summing up its

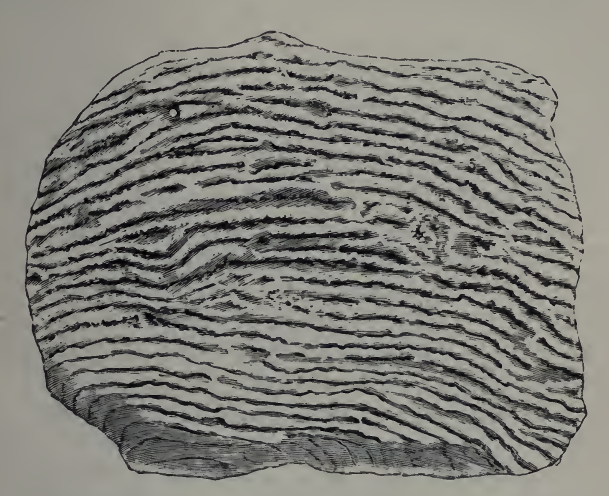


FIG. 5.—Weathered Specimen of Eozoon from the Calumet. (Collected by Mr. McMullen.)



FIG. 6.—Cross Section of the Specimen represented in Fig. 8. The dark parts are the laminæ of calcareous matter converging to the outer surface.

work to that time, was published, under the name of the "Geology of Canada," and in this, at page 49, will be found two figures of one of the Calumet specimens, here reproduced, and which, though unaccompanied with any specific name or technical description, were referred to as probably Laurentian fossils. (Figs. 5 and 6.)

About this time Dr. Hunt happened to mention to me, in connection with a paper on the mineralization of fossils which he was preparing, that he proposed to notice the mode of preservation of certain fossil woods and other things with which I was familiar, and that he would show me the paper in proof, in order that I might give him any suggestions that occurred to me. On reading it, I observed, among other things, that he alluded to the supposed Laurentian fossils, under the impression that the organic part was represented by the serpentine or loganite, and that the calcareous matter was the filling of the chambers. I took exception to this, stating that though in the slices I had examined no structure was apparent, still my impression was that the calcareous matter was the fossil, and the serpentine or loganite the filling. He said—"In that case, would it not be well to re-examine the specimens, and try to discover which view is correct?" He mentioned, at the same time, that Sir William had recently shown him some new and beautiful specimens collected by Mr. Lowe, one of the explorers on the staff of the Survey, from a third locality, at Grenville, on the Ottawa. It was supposed that these might throw further light on the subject; and accordingly Dr. Hunt suggested to Sir William to have additional slices of these new specimens made by Mr. Weston, of the Survey, whose skill as a preparer of these and other fossils has often done good service to science. A few days thereafter some slices were sent to me, and were at once put under the microscope. I was delighted to find in one of the first specimens examined a beautiful group of tubuli penetrating

one of the calcite layers. Here was evidence, not only that the calcite layers represented the true skeleton of the fossil, but also of its affinities with the foraminifera, whose tubulated supplemental skeleton, as described and figured by Dr. Carpenter, and represented in specimens in my collection, presented by him, was apparently of the same type with that preserved in the canals of these ancient fossils. Fig. 7 is an accurate representation of the group of canals first detected by me.

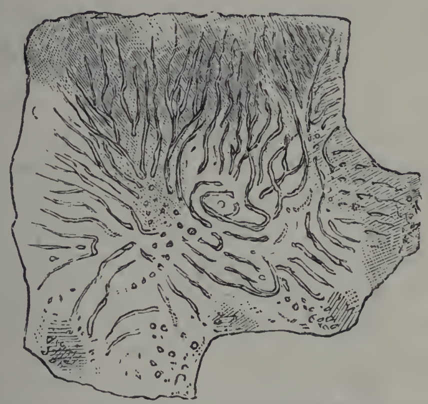


FIG. 7.—Group of Canals in the Supplemental Skeleton of Eozoon. Taken from the specimen in which they were first recognised. Magnified. (Camera tracing by Mr. H. S. Smith.)

On showing the structures discovered to Sir William Logan, he entered into the matter with enthusiasm, and had a great number of slices, as well as decalcified specimens, prepared, which were placed in my hands for examination.

Feeling that the discovery was most important, but that it would be met with determined scepticism by a great many geologists, I was not content with examining the typical specimens of Eozoon, but had slices prepared of every variety of

Laurentian limestone, of altered limestones from the Primordial and Silurian, and of serpentine marbles of all the varieties furnished by our collections. They were examined with ordinary and polarized light, and with every variety of illumination. They were also examined as decalcified specimens, after the carbonate of lime had been removed by acids. An extensive series of notes and camera tracings were made of all the appearances observed; and of some of the more important structures beautiful drawings were executed by the late Mr. H. S. Smith, the then palæontological draughtsman of the Survey. The result of the whole investigation was a firm conviction that the structure was organic and foraminiferal, and that it could be distinguished from any merely mineral or crystalline forms occurring in these or other limestones.

At this stage of the matter, and after exhibiting to Sir William all the characteristic appearances, in comparison with such concretionary, dendritic and crystalline structures as most resembled them, and also with the structure of recent and fossil Foraminifera, I suggested that the further prosecution of the matter should be handed over to Mr. Billings, as palæontologist of the Survey. I was engaged in other researches, not connected with the Survey or with this particular department, and I knew that no little labour must be devoted to the work and to its publication, and that some controversy might be expected. Mr. Billings, however, with his characteristic caution and modesty, declined. His hands were full of other work. He had not given any special attention to the microscopic appearances of Foraminifera or of mineral substances. It was finally arranged that I should prepare a description of the fossil, which Sir William would take to London, along with the more important specimens, and a detailed list stating all the structures observed in each. Sir William was to submit the manuscript and specimens to Dr. Carpenter, or, failing him, to Prof. T. Rupert Jones, in the hope that these

eminent authorities would confirm my conclusions, and bring forward new facts which I might have overlooked or been ignorant of. Sir William saw both gentlemen, who gave their testimony in favour of the organic and foraminiferal character of the specimens; and Dr. Carpenter, in particular, gave much attention to the subject, and worked out more in detail many of the finer structures, besides contributing valuable suggestions as to the probable affinities of the supposed fossil.

Dr. Carpenter thus contributed in a very important manner to the perfecting of the investigations begun in Canada, and on him fell the greater part of their illustration and defence,[1] in so far as Great Britain is concerned.

The immediate result was a composite paper in the *Proceedings of the Geological Society*, by Sir W. E. Logan, Dr. Carpenter, Dr. Hunt, and myself, in which the geology, palæontology and mineralogy of *Eozoon Canadense* and its containing rocks were first given to the world.[2] It cannot be wondered at that when geologists and palæontologists were thus required to believe in the existence of organic remains in rocks regarded as altogether Azoic and hopelessly barren of fossils, and to carry back the dawn of life as far before those Primordial rocks, which were supposed to contain its first traces, as these are before the middle period of the earth's life history, some hesitation should be felt. Further, the accurate appreciation of the evidence for such a fossil as Eozoon required an amount of knowledge of minerals, of the more humble types of animals, and of the conditions of mineralization of organic remains, possessed by few even of professional geologists. Thus Eozoon has met with some scepticism and not a little opposition,—though the latter has been weaker than we might have expected when

[1] In *Quarterly Journal of Geological Society*, vol. xxii.; *Proc. Royal Society*, vol. xv.; *Intellectual Observer*, 1865. *Annals and Magazine of Natural History*, 1874; and other papers and notices.

[2] *Journal Geological Society*, February, 1865.

we consider the startling character of the facts adduced, and has mostly come from men imperfectly informed.

But what is Eozoon, if really of animal origin? The shortest answer to this question is, that this ancient fossil is supposed to be the skeleton of a creature belonging to that simple and humbly organized group of animals which are known by the name Protozoa. If we take as a familiar example of these the gelatinous and microscopic creature found in stagnant ponds, and known as the *Amœba*[1] (Fig. 8), it will form a convenient starting-point. Viewed under a low power, it appears as a little patch of jelly, irregular in form, and constantly changing its aspect as it moves, by the extension of parts of its body into finger-like processes or pseudopods which serve as extempore limbs. When moving on the surface of a slip of glass under the microscope, it seems, as it were, to flow along rather than creep, and its body appears to be of a semi-fluid consistency. It may be taken as an example of the least complex forms of animal life known to us, and is often spoken of by naturalists as if it were merely a little particle of living and scarcely organized jelly or protoplasm. When minutely examined, however, it will not be found so simple as it at first sight appears. Its outer layer is clear and transparent, and more dense than the inner mass, which seems granular. It has at one end a curious vesicle which can be seen gradually to expand and become filled with a clear drop of liquid, and then suddenly to contract and expel the contained fluid through a series of pores in the adjacent part of the outer wall. This is the so-called pulsating vesicle, and is an organ both of circulation and excretion. In another part of the body may be seen the nucleus, which is a little cell capable, at certain times, of producing by its division new individuals. Food, when taken in through the wall of the body, forms little pellets, which become surrounded by a

[1] The alternating animal, alluding to its change of form.

digestive liquid exuded from the enclosing mass into rounded cavities or extemporised stomachs. Minute granules are seen to circulate in the gelatinous interior, and may be substitutes for blood-cells, and the outer layer of the body is capable of protrusion in any direction into long processes, which are very mobile, and used for locomotion and prehension. Further, this creature, though destitute of most of the parts which we are accustomed to regard as proper to animals, seems to exercise volition, and to show the same appetites and passions with animals of higher type. I have watched one of these animal-

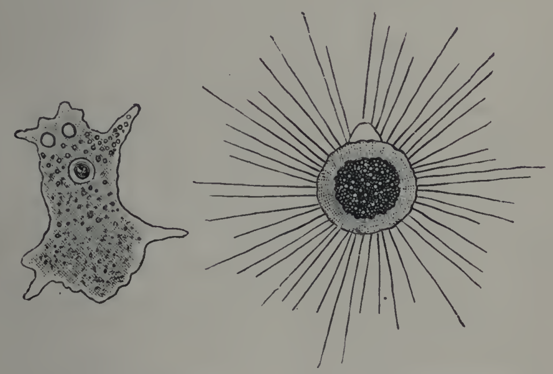


FIG. 8. Amœba. FIG. 9. Actinophrys.
From original sketches.

cules endeavouring to swallow a one-celled plant as long as its own body; evidently hungry and eager to devour the tempting morsel, it stretched itself to its full extent, trying to envelope the object of its desire. It failed again and again; but renewed the attempt, until at length, convinced of its hopelessness, it flung itself away as if in disappointment, and made off in search of something more manageable. With the Amœba are found other types of equally simple Protozoa, but somewhat differently

organized. One of these, *Actinophrys* (Fig. 9), has the body globular and unchanging in form, the outer wall of greater thickness; the pulsating vesicle like a blister on the surface, and the pseudopods long and thread-like. Its habits are similar to those of the Amœba, and I introduce it to show the variations of form and structure possible even among these simple creatures.

The Amœba and Actinophrys are fresh-water animals, and are destitute of any shell or covering. But in the sea there exist swarms of similar creatures, equally simple in organization, but gifted with the power of secreting around their soft bodies beautiful little shells or crusts of carbonate of lime, having one orifice, and often in addition multitudes of microscopic pores through which the soft gelatinous matter can ooze, and form outside finger-like or thread-like extensions for collecting food. In some cases the shell consists of a single cavity only, but in most, after one cell is completed, others are added, forming a series of cells or chambers communicating with each other, and often arranged spirally or otherwise in most beautiful and symmetrical forms. Some of these creatures, usually named Foraminifera, are locomotive, others sessile and attached. Most of them are microscopic, but some grow by multiplication of chambers till they are a quarter of an inch or more in breadth.

The original skeleton or primary cell wall of most of these creatures is seen under the miscroscope to be perforated with innumerable pores, and is extremely thin. When, however, owing to the increased size of the shell, or other wants of the creature, it is necessary to give strength, this is done by adding new portions of carbonate of lime to the outside, and to these Dr. Carpenter has given the appropriate name of "supplemental skeleton"; and this, when covered by new growths, becomes what he has termed an "intermediate skeleton." The supplemental skeleton is also traversed by tubes, but these are

often of larger size than the pores of the cell-wall, and of greater length, and branched in a complicated manner. Thus there are microscopic characters by which these curious shells can be distinguished from those of other marine animals; and by applying these characters we learn that multitudes of creatures of this type have existed in former periods of the world's history, and that their shells, accumulated in the bottom of the sea, constitute large portions of many limestones. The manner in which such accumulation takes place we learn from what is now going on in the ocean, more especially from the result of the recent deep-sea dredging expeditions. The Foraminifera are vastly numerous, both near the surface and at the bottom of the sea, and multiply rapidly; and as successive generations die, their shells accumulate on the ocean bed, or are swept by currents into banks, and thus, in process of time, constitute thick beds of white chalky material, which may eventually be hardened into limestone. This process is now depositing a great thickness of white ooze in the bottom of the ocean; and in times past it has produced such vast thicknesses of calcareous matter as the chalk and nummulitic limestone of Europe and the orbitoidal limestone of America. The chalk which alone attains a maximum thickness of 1,000 feet, and, according to Lyell, can be traced across Europe for 1,100 geographical miles, may be said to be entirely composed of shells of Foraminifera imbedded in a paste of smaller calcareous bodies, the Coccoliths, which are probably products of marine vegetable life, if not of some animal organism still simpler than the Foraminifera.

Lastly, while we have in such modern forms as the masses of Polytrema attached to corals, and the Loftusia of the Eocene and the carboniferous, large fossil foraminiferal species, there is some reason to believe that in the earlier geological ages there existed much larger animals of this grade than are found in our present seas; and that these, always

sessile on the bottom, grew by the addition of successive chambers, in the same manner with the smaller species.[1]

Let us, then, examine the structure of Eozoon, taking a typical specimen, as we find it in the limestone of Grenville or Petite Nation. In such specimens the skeleton of the animal is represented by a white crystalline marble, the cavities of the cells by green serpentine, the mode of whose introduction we shall have to consider in the sequel. The lowest layer of serpentine represents the first gelatinous coat of animal matter which grew upon the bottom, and which, if we could have seen it before any shell was formed upon its surface, must have resembled a minute patch of living slime. On this primary layer grew a delicate calcareous shell, perforated by innumerable minute tubuli, and resting on the slimy matter of the animal, though supported also by some perpendicular plates or septa. Upon this again was built up, in order to strengthen it, a thickening or supplemental skeleton, more dense, and destitute of fine tubuli, but traversed by branching canals, through which the soft gelatinous matter could pass for the nourishment of the skeleton itself, and the extension of pseudopods beyond it. (Figs. 11, 12.) So was formed the first layer of Eozoon, which probably was at its beginning only of very small dimensions. On this the process of growth of successive layers of animal sarcode and of calcareous skeleton was repeated again and again, till in some cases even a hundred or more layers were formed (nature-print, Chap. VI.) As the process went on, however, the vitality of the organism became exhausted, probably by the deficient nourishment of the central and lower layers making greater and greater demands on those above, and so the succeeding layers became thinner, and less supplemental skeleton was developed. Finally, toward the top, the regular arrangement in layers was abandoned, and the cells

[1] I refer to some of the Stromatoporæ of the Silurian and the *Cryptozoon* of the Cambrian. See note appended to this chapter.

became a mass of rounded chambers, irregularly piled up in what Dr. Carpenter has termed an "acervuline" manner, and with very thin walls unprotected by supplemental skeleton. Then the growth was arrested, and possibly these upper layers gave off reproductive germs, fitted to float or swim away and to establish new colonies. We may have such reproductive germs in certain curious globular bodies, like loose cells, found in connection with Eozoon in many of the Laurentian lime-

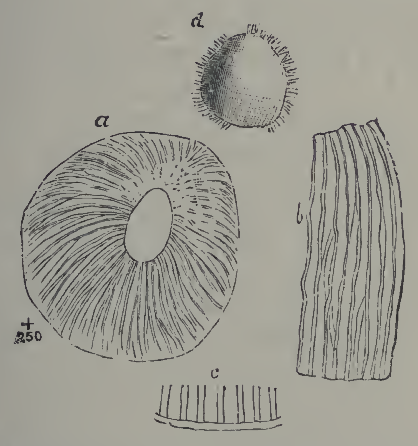


FIG. 10.—Minute Foraminiferal forms from the Laurentian of Long Lake. Highly magnified. (*a*) Single cell, showing tubulated wall. (*b*, *c*) Portions of same more highly magnified. (*d*) Serpentine cast of a similar chamber, decalcified, and showing casts of tubuli.

stones.[1] At St. Pierre, on the Ottawa, these bodies occur on the surface of layers of the limestone in vast numbers, as if they had been growing separately on the bottom, or had been drifted over it by currents. They may have served as repro-

[1] It would be interesting to compare these bodies with the forms recently found by Barrois and Cayeux in the "Azoic" quartzite of Brittany, which should certainly now be called Eozoic.

7

ductive buds or germs to establish new colonies of the species. Such was the general mode of growth of Eozoon, and we may now consider more in detail some questions as to its gigantic size, its precise mode of nutrition, the arrangement of its parts, its relations to more modern forms, and the effects of its growth in the Laurentian seas.

With respect to the size of Eozoon, this was rivalled by some succeeding animals of the same humble type in later geological ages; and, as a whole, foraminiferal animals have been diminishing in size in the lapse of geological time. This is indeed a fact of so frequent occurrence that it may almost be regarded as a law of the introduction of new forms of life, that they assume in their early history gigantic dimensions, and are afterwards continued by less magnificent species. The relations of this to external conditions, in the case of higher animals, are often complex and difficult to understand; but in organisms so low as Eozoon and its allies, they lie more on the surface. Such creatures may be regarded as the simplest and most ready media for the conversion of vegetable matter into animal tissues, and their functions are almost entirely limited to those of nutrition. Hence it is likely that they will be able to appear in the most gigantic forms under such conditions as afford them the greatest amount of pabulum for the nourishment of their soft parts and for their skeletons. There is reason to believe, for example, that the occurrence, both in the chalk and the deep-sea mud, of immense quantities of the minute bodies known as Coccoliths along with Foraminifera, is not accidental. The Coccoliths appear to be grains of calcareous matter formed in minute plants adapted to a deep-sea habitat; and these, along with the vegetable and animal *débris* constantly being derived from the death of the living things at the surface, afford the material both of sarcode and shell. Now if the Laurentian graphite represents an exuberance of vegetable growth in those old seas propor-

tionate to the great supplies of carbonic acid in the atmosphere and in the waters, and if the Eozoic ocean was even better supplied with salts of lime than those Silurian seas whose vast limestones bear testimony to their richness in such material, we can easily imagine that the conditions may have been more favourable to a creature like Eozoon than those of any other period of geological time.

Growing, as Eozoon did, on the floor of the ocean, and covering wide patches with more or less irregular masses, it must have thrown up from its whole surface its pseudopods to seize whatever floating particles of food the waters carried over it. There is also reason to believe, from the outline of certain specimens, that it often grew upward in conical or club-shaped forms, and that the broader patches were penetrated by large pits or oscula, admitting the sea-water deeply into the substance of the masses. In this way its growth might be rapid and continuous; but it does not seem to have possessed the power of growing indefinitely by new and living layers covering those that had died, in the manner of some corals. Its life seems to have had a definite termination, and when that was reached, an entirely new colony had to be commenced. In this it had more affinity with the Foraminifera, as we now know them, than with the corals, though practically it had the same power with the coral polyps of accumulating limestone in the sea bottom—a power indeed still possessed by its foraminiferal successors. In the case of coral limestones we know that a large proportion of these consist not of continuous reefs, but of fragments of coral mixed with other calcareous organisms, spread usually by waves and currents in continuous beds over the sea bottom. In like manner we find in the limestones containing Eozoon, layers of fragmental matter which show in places the characteristic structures, and which evidently represent the *débris* swept from the Eozoic masses and reefs by the action of the waves. It is with this frag-

mental matter that the small rounded organisms already referred to most frequently occur; and while they may be distinct animals, they may also be the fry of Eozoon, or small portions of its acervuline upper surface floated off in a living state, and possibly capable of living independently and of founding new colonies.

It is only by a somewhat wild poetical licence that Eozoon has been represented as a "kind of enormous composite animal stretching from the shores of Labrador to Lake Superior, and thence northward and southward to an unknown distance, and forming masses 1,500 feet in depth." We may, it is true, readily believe in the composite nature of masses of Eozoon, and we see in the corals evidence of the great size to which composite animals of a higher grade can attain. In the case of Eozoon we must imagine an ocean floor more uniform and level than that now existing. On this the organism would establish itself in spots and patches. These might finally become confluent over large areas, just as massive corals do. As individual masses attained maturity and died, their pores would be filled up with limestone or silicious deposits, and thus could form a solid basis for new generations, and in this way limestone to an indefinite extent might be produced. Further, wherever such masses were high enough to be attacked by the breakers, or where portions of the sea bottom were elevated, the more fragile parts of the surface would be broken up and scattered widely in beds of fragments over the bottom of the sea, while here and there beds of mud or sand, or of volcanic *débris* would be deposited over the living or dead organic mass, and would form the layers of gneiss and other schistose rocks interstratified with the Laurentian limestone. In this way, in short, Eozoon would perform a function combining that which corals and Foraminifera perform in the modern seas; forming both reef limestones and extensive chalky beds, and probably living both in the shallow and

the deeper parts of the ocean. If in connection with this we consider the rapidity with which the soft, simple, and almost structureless sarcode of these Protozoa can be built up, and the probability that they were more abundantly supplied with food, both for nourishing their soft parts and skeletons, than any similar creatures in later times, we can readily understand the great volume and extent of the Laurentian limestones which they aided in producing. I say aided in producing, because I would not care to commit myself to the doctrine that the Laurentian limestones are wholly of this origin. There may have been other limestone builders than Eozoon,



FIG. 11.—Section of a Nummulite, from Eocene Limestone of Syria. Showing chambers, tubuli, and canals. Compare this and Fig. 12 with Fig. 7 and Nature-print of Eozoon.

and there may have been limestones formed by plants like the modern Nullipores, or by merely mineral deposition.

Its relations to modern animals of its type have been very clearly defined by Dr. Carpenter. In the structure of its proper wall and its fine parallel perforations, it resembles the *Nummulites* and their allies; and the organism may therefore be regarded as an aberrant member of the Nummuline group, which affords some of the largest and most widely distributed of the fossil Foraminifera. This resemblance may be seen in Fig. 11. To the Nummulites it also conforms in its tendency to form a supplemental or intermediate skeleton with canals,

though the canals themselves in the arrangement more nearly resemble Calcarina, which is represented in Fig. 12. In its superposition of many layers, and in its tendency to a heaped up or acervuline irregular growth it resembles *Polytrema* and *Tinoporus*, forms of a different group in so far as shell-structure is concerned. It may thus be regarded as a composite type, combining peculiarities now observed in two groups, or it may be regarded as representing one of these in another series. At the time when Dr. Carpenter stated these

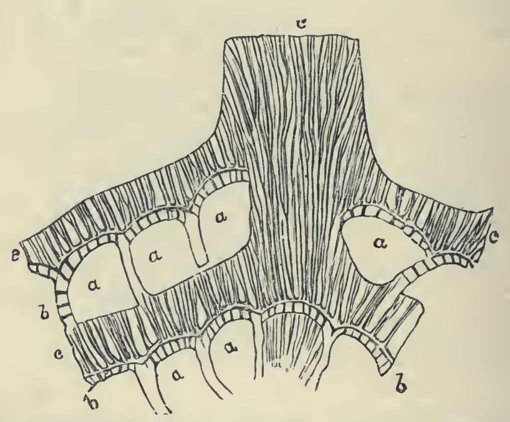


FIG. 12.—Portion of shell of Calcarina. Magnified, after Carpenter. (*a*) Cells. (*b*) Original cell wall with tubuli. (*c*) Supplementary skeleton with canals.

affinities, it might be objected that Foraminifera of these families are in the main found in the modern and Tertiary periods. Dr. Carpenter has since shown that the curious oval Foraminifer called *Fusulina*, found in the coal formation, is allied to both Nummulites and Rotalines ; and Mr. Brady has discovered a true Nummulite in the Lower Carboniferous of Belgium. I have myself found small Foraminifera in the Silurian and Cambro-Silurian of Canada. This group being

now brought down to the Palæozoic, we may hope to trace it to the Primordial, and thus to bring it still nearer to Eozoon in time.

Though Eozoon was probably not the only animal of the Laurentian seas, yet it was in all likelihood the most conspicuous and important as a collector of calcareous matter, filling the same place afterwards occupied by the reef-building corals. Though probably less efficient than these as a constructor of solid limestones, from its less permanent and continuous growth, it formed wide floors and patches on the sea bottom, and when these were broken up, vast quantities of limestone were formed from their *débris*. It must also be borne in mind that Eozoon was not everywhere infiltrated with serpentine or other silicious minerals ; quantities of its substance were merely filled with carbonate of lime, resembling the chamber wall so closely that it is nearly impossible to make out the difference, and thus is likely to pass altogether unobserved by collectors, and to baffle even the microscopist. Although, therefore, the layers which contain well characterised Eozoon are few and far between, there is reason to believe that in the composition of the limestones of the Laurentian it bore no small part, and as these limestones are some of them several hundred feet in thickness, and extend over vast areas, Eozoon may be supposed to have been as efficient a world-builder as the Stromatoporæ of the Silurian and Devonian, the Globigerinæ and their allies in the chalk, or the Nummulites and Miliolites in the Eocene. It is a remarkable illustration of the constancy of natural causes and of the persistence of animal types, that these humble Protozoans, which began to secrete calcareous matter in the Laurentian period, have been continuing their work in the ocean through all the geological ages, and are still busy in accumulating those chalky muds with which recent dredging operations in the deep sea have made us so familiar. (See Note appended.)

All this seems sufficiently reasonable, more especially since

no mineralogist has yet succeeded in giving a feasible inorganic explanation of the combination of canals, laminæ, tubulation and varied mineral character existing in Eozoon. But then comes the strange fact of its apparent isolation without companions in highly crystalline rocks, and with apparently no immediate successors. This has staggered many, and it certainly, if taken thus baldly, seems in some degree improbable. Recent discoveries, however, are removing this reproach from Eozoon. The Laurentian rocks have yielded other varieties, or perhaps species of the genus, those which I have described as variety Acervulina, and variety Minor, and still another form, more like a Stromatopora, which I have provisionally named *E. latior*, from the breadth and uniformity of its plates.[1] There are also in the Laurentian limestone cylindrical bodies apparently originally tubular, and with the sides showing radiating markings in the manner of corals, or of the curious Cambrian Archæocyathus. Matthew, a most careful observer, has found in the Laurentian limestone of New Brunswick certain laminated bodies of cylindrical form, constituting great reefs in the limestone, and in the slates linear flat objects resembling Algæ or Graptolites, and spicular structures resembling those of sponges.[2] Britton has also described from the Laurentian limestone of New Jersey certain ribbon-like objects of graphite which he regards as vegetable, and names *Archæophyton Newberryii*.[3] Should these objects prove to be organic, Eozoon will no longer be alone. Besides this the peculiar bodies named Cryptozoum by Hall, and which are intermediate in structure between Eozoon and Loftusia, have now been found as low as the Lower Cambrian.[4] Barrois

[1] Notes on Specimens of Eozoon, "Memoirs of Peter Redpath Museum," 1888.

[2] *Bul. Nat. Hist. New Brunswick, No. IX.*, 1890.

[3] *Annals N. Y. Academy of Science*, 1888.

[4] Walcott, Lower Cambrian, 1892.

has also recently announced the discovery of forms which he regards as akin to the modern Radiolaria, creatures of a little higher grade than the Foraminifera, in the "Archæan" rocks of Brittany.[1] Thus Eozoon is no longer isolated, but has companions of the same great age with itself. The progress of discovery is also daily carrying the life of the Cambrian to lower beds, and thus nearer to the Laurentian. It is not unlikely that in a few years a pre-Cambrian fauna will force itself on the attention of the most sceptical geologists.

REFERENCES:—"Life's Dawn on Earth," London, 1875. (Now out of print.) "Specimens of Eozoon Canadense in the Peter Redpath Museum, Montreal," 1888. (This memoir contains reference to previous papers.)

[1] *Natural Science*, Oct., 1892.

APPENDED NOTES.

1. *Stromatoporæ.*—It has been usual of late to regard these as allies of the modern Millepores and Hydractineæ; but careful study of large series of specimens has convinced me that some species, notably the *Stromatocerium* of the Cambro-Silurian and the *cryptozoum* of the Cambrian, cannot be so referred. I hope to establish this in the future, if time permit.

2. MODERN FORAMINIFERA.—The discovery by Brady and Lister of reproductive chamberlets at the margin of the modern *orbitolites*, tends to connect this with Eozoon. The gigantic foraminiferal species discovered by Agassiz at the Gallipagos, has points of affinity with Eozoon; and its arenaceous nature does not affect this, as we know sandy species in this group closely allied to others that are calcareous.



WHAT MAY BE LEARNED FROM EOZOON.

DEDICATED TO THE MEMORY OF

DR. WILLIAM B. CARPENTER,

WHO, AMONG HIS MANY SERVICES TO SCIENCE,
DEVOTED MUCH TIME AND LABOUR TO THE INVESTIGATION
OF EOZOON,
AND BY HIS KNOWLEDGE OF FORAMINIFERA
AND UNRIVALLED POWER OF UNRAVELLING DIFFICULT
STRUCTURES
DID MUCH TO RENDER IT INTELLIGIBLE.

THE MICROSCOPE IN GEOLOGY—CONTRIBUTIONS OF THE STUDY OF EOZOON TO OUR KNOWLEDGE OF THE MODE OF PRESERVATION OF FOSSILS—ITS TEACHING RELATIVELY TO THE ORIGIN OF LIFE AND THE LAWS OF ITS INTRODUCTION AND PROGRESS





Specimen of Eozoon Canadense (Dawson), showing General Form and Osculiform Tubes. (Reproduced from Photograph.)

CHAPTER VI.

WHAT MAY BE LEARNED FROM EOZOON.

THE microscope has long been a recognised and valued aid of the geological observer, and is perhaps now in danger of being somewhat overrated by enthusiastic specialists. To the present writer its use is no novelty. When, as a very young geologist, collecting fossil plants in the coal fields of Novia Scotia, I obtained access to the then recently published work of Witham on the "Internal Structure of Fossil Vegetables."[1] Fired by the desire to learn something of the structure of the blocks of fossil wood in my collection, I at once procured a microscope of what would now be considered a very imperfect kind, and proceeded to make attempts to slice and examine my specimens, and was filled with joy when these old blackened stems for the first time revealed to me their wonderful structures. At the same time I extended my studies to every minute form of life that could be obtained from the sea or fresh waters. A few years later (in 1841), when a student in Edinburgh, I made the acquaintance of Mr. Sanderson of that city, who had worked for Nicol and Witham in the preparation of specimens, and learnt the modes which he had employed. Since that time I have been accustomed to subject every rock, earth or fossil which came under my notice to microscopic scrutiny, not as a mere specialist in that mode of observation, or with the parade of methods and details now customary, but with the view of obtaining valuable facts bear-

[1] Edinburgh, 1833.

ing on any investigation I might have in hand. It was this habit which induced my old friend, Sir William Logan, in 1858 and subsequent years to ask my aid in the study of the forms believed or suspected to be organic, which had been discovered in the course of his surveys of the Laurentian rocks. In one respect this was unfortunate. It occupied much time, interfered to some extent with other researches, led to unpleasant controversies. But these evils were more than compensated by the insight which the study gave into the fact of the persistence of organic structures in highly crystalline rocks, and to the modes of ascertaining and profiting by these obscure remains, while it has guided and stimulated enquiry and thought as to the origin and history of life. These benefits entitle the researches and discussions on Eozoon to be regarded as marking a salient point in the history of geological discovery, and it is to these principally that I would attract attention in the present chapter.

Perhaps nothing excites more scepticism as to the animal nature of Eozoon than the prejudice existing among geologists that no organism can be preserved in rocks so highly crystalline as those of the Laurentian series. I call this a prejudice, because any one who makes the microscopic structure of rocks and fossils a special study, soon learns that fossils and the rocks containing them may undergo the most remarkable and complete mechanical and chemical changes without losing their minute structure, and that limestones, if once fossiliferous, are hardly ever so much altered as to lose all traces of the organisms which they contained, while it is a most common occurrence to find highly crystalline rocks of this kind abounding in fossils preserved as to their minute structure.

Let us, however, look at the precise conditions under which this takes place.

When calcareous fossils of irregular surface and porous or cellular texture, such as Eozoon may have been, or corals were

and are, become imbedded in clay, marl, or other soft sediment, they can be washed out and recovered in a condition similar to that of recent specimens, except that their pores or cells, if open, may be filled with the material of the matrix, or if not so open that they can be thus filled, they may be more or less incrusted with mineral deposits introduced by water percolating the mass, or may even be completely filled up in this way. But if such fossils are contained in hard rocks, they usually fail, when these are broken, to show their external surfaces, and, breaking across with the containing rock, they exhibit their internal structure merely,—and this more or less distinctly, according to the manner in which their cells or cavities have been filled with mineral matter. Here the microscope becomes of essential service, especially when the structures are minute. A fragment of fossil wood which to the naked eye is nothing but a dark stone, or a coral which is merely a piece of grey or coloured marble, or a specimen of common crystalline limestone made up originally of coral fragments, presents, when sliced and magnified, the most perfect and beautiful structure. In such cases it will be found that ordinarily the original substance of the fossil remains in a more or less altered state. Wood may be represented by dark lines of coaly matter, or coral by its white or transparent calcareous laminæ; while the material which has been introduced, and which fills the cavities, may so differ in colour, transparency, or crystallization, as to act differently on light, and so reveal the original structure. These fillings are very curious. Sometimes they are mere earthy or muddy matter which has been washed into the cavities. Sometimes they are transparent and crystalline. Often they are stained with oxide of iron or coaly materials. They may consist of carbonate of lime, silica or silicates, sulphate of baryta, oxides of iron, carbonate of iron, iron pyrite, or sulphides of copper or lead, all of which are common materials. They are sometimes so complicated that

I have seen even the minute cells of woody structures, each with several bands of differently coloured materials deposited in succession, like the coats of an onyx agate.

A further stage of mineralisation occurs when the substance of the organism is altogether removed and replaced by foreign matter, either little by little, or by being entirely dissolved or decomposed, leaving a cavity to be filled by infiltration. In this state are some silicified woods, and those corals which have been not filled with but replaced by silica, and can thus sometimes be obtained entire and perfect by the solution in an acid of the containing limestone, or by its removal in weathering. In this state are the beautiful silicified corals obtained from the corniferous limestone of Lake Erie, which are so perfectly replaced by flinty matter that when weathered out of the limestone, or treated with acid till the latter is removed, we find the coral as perfect as when recent. It may be well to present to the eye these different stages of fossilization. I have attempted to do this in Fig. 13, taking a tabulate coral of the genus Favosites for an example, and supposing the material employed to be calcite and silica. Precisely the same illustration would apply to a piece of wood, except that the cell wall would be carbonaceous matter instead of carbonate of lime. In this figure the dotted parts represent carbonate of lime, the diagonally shaded parts silica or a silicate. Thus we have in the natural state the walls of carbonate of lime and the cavities empty (*a*). When fossilized the cavities may be merely filled with carbonate of lime, or they may be filled with silica (*b*, *c*); or the walls themselves may be replaced by silica, and the cavities may remain filled with carbonate of lime (*d*); or both the walls and cavities may be represented by or filled with silica or silicates (*e*). The ordinary specimens of Eozoon are supposed to be in the third of these stages, though some exist in the second, and I have reason to believe that some have reached to the fifth. I have not met with any in the

fourth stage, though this is not uncommon in Silurian and Devonian fossils. I have further to remark that the reason why wood and the cells of corals so readily become silicified is that the organic matter which they contain, becoming oxidized in decay, produces carbon dioxide, which, by its affinity for alkalies, can decompose soluble silicates and thus throw down their silica in an insoluble state. Thus a fragment of decaying wood imbedded in a deposit holding water and alkaline silicates almost necessarily becomes silicified. It is also to be remarked that the ordinary specimens of Eozoon have actually not attained to the extreme degree of mineralization seen in some much more recent silicified woods and corals, inasmuch

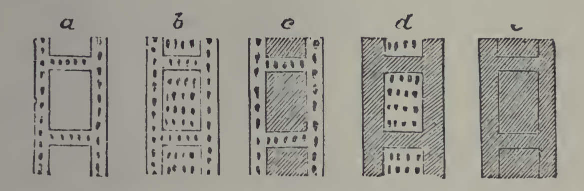


FIG. 13.—Diagram showing different States of Fossilization of a cell of a Tabulate Coral. (*a*) Natural condition—walls calcite, cell empty. (*b*) Walls calcite, cell filled with the same. (*c*) Walls calcite, cell filled with silica or silicate. (*d*) Walls silicified, cell filled with calcite. (*e*) Walls silicified, cell filled with silica or silicate.

as the portion believed to have been the original calcareous test has not usually been silicified, but still remains in the state of calcium carbonate.

With regard, then, to the calcareous organisms with which we have now more especially to do, when these are embedded in pure limestone and filled with the same, so that the whole rock, fossils and cavities, is one in composition, and when metamorphic action has caused the whole to become crystalline, and has perhaps removed the remains of carbonaceous matter, it may be very difficult to detect any traces of structure. But

even in this case careful management of light may reveal some indications. In many instances, however, even where the limestones have become perfectly crystalline, and the cleavage planes cut freely across the fossils, these exhibit their forms and minute structures in great perfection. This is the case in many of the Lower Silurian limestones of Canada, as I have elsewhere shown.[1] The grey crystalline Trenton limestone of Montreal, used as a building stone, is an excellent illustration. To the naked eye it is a grey marble composed of cleavable crystals; but when examined in thin slices, it shows its organic fragments in the greatest beauty, and all their minute parts are perfectly marked out by delicate carbonaceous lines. The only exception in this limestone is in the case of the crinoids, in which the cellular structure is filled with transparent calc-spar, perfectly identical with the original solid matter, so that they appear solid and homogeneous, but there are examples in which even the minute meshes of these become apparent. The specimen represented in Fig. 14 is a mass of Corals, Polyzoa, and Crinoids, and shows these under a low power, as represented in the figure. The specimen in Fig. 15 shows the Laurentian Eozoon in a similar state of preservation. It is from a sketch by Dr. Carpenter, and exhibits the delicate canals partly filled with calcite or dolomite, as clear and colourless as that of the shell itself, and distinguishable only by careful management of the light.

In the case of recent and fossil Foraminifers, these very frequently have their chambers filled solid with calcareous matter, and as Dr. Carpenter well remarks, even well preserved Tertiary Nummulites in this state often fail greatly in showing their structures, though in the same condition they occasionally show these in great perfection. Among the finest I have seen are specimens from the Mount of Olives, and Dr. Carpenter

[1] *Canadian Naturalist*, 1859: "Microscopic Structure of Canadian Limestones."

mentions as equally good those of the London clay at Bracklesham. But in no condition do modern Foraminifera, or those of the Tertiary and Mesozoic rocks appear in greater perfection than when filled with the hydrous silicate of iron and potash

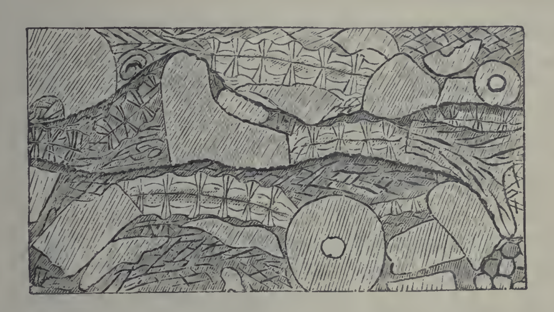


FIG. 14.—Slice of Crystalline Lower Silurian Limestone; showing Crinoids, Bryozoa, and Corals in fragments.

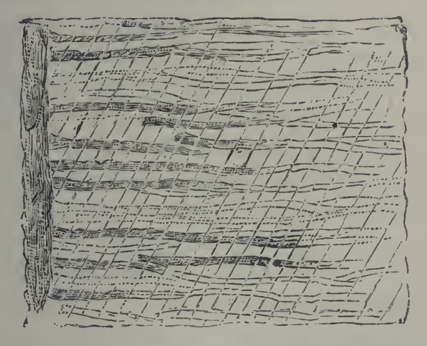


FIG. 15.—Walls of Eozoon penetrated with Canals. The unshaded portions filled with Calcite. (After Carpenter.)

called glauconite or green earth, a substance now forming in some parts of the ocean, and which gives, by the abundance of its little bottle-green concretions the name of "greensand" to formations of the Cretaceous age both in Europe and America.

In some beds of greensand every grain seems to have been moulded into the interior of a microscopic shell, and has retained its form after the frail envelope has been removed. In some cases the glauconite has not only filled the chambers but has penetrated the fine tubulation, and when the shell is removed, either naturally or by the action of an acid, the silicious fillings of the interior of the tubes project in minute needles or bundles of threads of marvellous delicacy from the surface of the cast. It is in the warmer seas, and especially in the bed of the Egean and of the Gulf Stream, that such specimens are now most usually found.[1] If we ask why this mineral glauconite should be associated with foraminiferal shells, the answer is that they are both products of one kind of locality. The same sea bottoms in which Foraminifera most abound are also those in which the chemical conditions for the formation of glauconite exist. Hence, no doubt, the association of this mineral with the great foraminiferal formation of the chalk. It is indeed by no means unlikely that the selection by these creatures of the pure carbonate of lime from the sea water or its minute plants, may be the means of setting free the silica, iron, and potash, in a state suitable for their combination. Similar silicates are found associated with marine limestones, as far back as the Cambro-Silurian age; and Dr. Sterry Hunt, than whom no one can be a better authority on chemical geology, has argued on chemical grounds that the occurrence of serpentine with the remains of Eozoon is an association of the same character.

However this may be, the infiltration of the pores of Eozoon with serpentine and other silicates has evidently been one main means of its preservation. When so infiltrated no metamorphism short of the complete fusion of the containing rock

[1] Beautiful specimens of Nummulites preserved in this way, from the Eocene of Kumpfen in Bavaria, have been communicated to me through the kindness of Dr. Otto Hahn.

could obliterate the minutest points of structure; and that such fusion has not occurred, the preservation in the Laurentian rocks of the most delicate lamination of the beds shows conclusively; while, as already stated, it can be shown that the alteration which has occurred might have taken place at a temperature far short of that necessary to fuse limestone. Thus has it happened that these most ancient fossils have been handed down to our time in a state of preservation comparable, as Dr. Carpenter states, to that of the best preserved fossil Foraminifera from the more recent formations that have come under his observation in the course of all his long experience.

Let us now look more minutely at the nature of the typical specimens of Eozoon as originally observed and described, and then turn to those preserved in other ways, or more or less destroyed or defaced. Taking a polished specimen from Petite Nation, we find the shell represented by white limestone, and the chambers by light green serpentine. By acting on the surface with a dilute acid we etch out the calcareous part, leaving a cast in serpentine of the cavities originally occupied by the soft animal substance, and when this is done in polished slices, these may be made to print their own characters on paper, as has actually been done in the plate prefixed, which is an electrotype from an etched specimen, and shows both the laminated and acervuline parts of the fossil. If the process of decalcification has been carefully executed, we find in the excavated spaces delicate ramifying processes of opaque serpentine or transparent dolomite, which were originally imbedded in the calcareous substance, and which are often of extreme fineness and complexity.[1] (Figs. 18, 19.) These are casts of the canals which traversed the shell when still inhabited by the animal, and have subsequently been filled with mineral

[1] Very fine specimens can be produced by polishing thin slices, and then etching them slightly with a very weak acid. (Plate prefixed.)

matter. In evidence of this we sometimes find in a single canal an outer tubular layer of serpentine and an inner filling of dolomite, just as vessels of fossil plants are sometimes filled with successive coats of different materials. In some well preserved specimens we find the original cell wall represented by a delicate white film, which under the microscope shows minute needle-like parallel processes representing its still finer tubuli. It is evident that to have filled these tubuli, the serpentine must have been introduced in a state of actual solution, and must have carried with it no foreign impurities. Consequently we find that in the chambers themselves the serpentine is pure; and if we examine it under polarized light, we see that it presents a singularly curdled or irregularly laminated appearance, as if it had an imperfectly crystalline structure, and had been deposited in irregular laminæ, beginning at the sides of the chambers, and filling them toward the middle, and had afterward been cracked by shrinkage, and the cracks filled with a second deposit of serpentine.[1] Now, serpentine is a hydrous silicate of magnesia, and all that we need to suppose is that in the waters of the Laurentian sea magnesia was present instead of iron, alumina or potash, and we can understand that the Laurentian fossil has been petrified by infiltration with serpentine, as more modern Foraminifera have been with glauconite, which, though it does not contain magnesia, often has a considerable percentage of alumina. Further, in specimens of Eozoon from Burgess, the filling mineral is loganite, a compound of silica, alumina, magnesia and iron with water, while in other specimens the filling mineral is pyroxene. In like

[1] The same structures may be well seen in thin slices polished, to be viewed as transparent objects. I may, however, explain that if these are made roughly, and heated in the process, they may often show only mineral structures and cleavage planes, whereas, if polished with great care and slowly, and afterwards cleaned with an acid, they may show the canals in great perfection.

manner, in certain Silurian limestones from New Brunswick and Wales, in which the delicate microscopic pores of the skeletons of stalked starfishes or crinoids have been filled with mineral deposits, so that when decalcified these are most beautifully represented by their casts, Dr. Hunt has proved the filling mineral to be[1] intermediate between serpentine and glauconite. We have, therefore, ample warrant for adhering to his con-



FIG. 16.—Joint of a Crinoid, having its Pores injected with a Hydrous Silicate. Upper Silurian Limestone, Pole Hill, New Brunswick. Magnified 25 diameters.

clusion that the Laurentian serpentine was deposited under conditions similar to those of the modern greensand. Indeed, independently of Eozoon, it is impossible that any geologist who has studied the manner in which this mineral is associated with the Laurentian limestones could believe it to have been

[1] Silicate of alumina, iron, magnesia, and potash.

formed in any other way. Nor need we be astonished at the fineness of the infiltration by which these minute tubes, perhaps $\frac{1}{10000}$ of an inch in diameter, are filled with mineral matter. The micro-geologist well knows how, in more modern deposits, the finest pores of fossils are filled, and that mineral matter in solution can penetrate the smallest openings that the microscope can detect. Wherever the fluids of the living body can penetrate, there also mineral substances can be carried, and

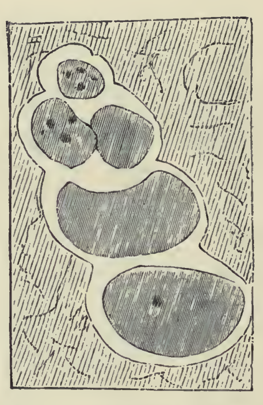


FIG. 17.—Shell from a Silurian Limestone, Wales; its cavity filled with Hydrous Silicate. Magnified 25 diameters.

this natural injection, effected under great pressure and with the advantage of ample time, can surpass any of the feats of the anatomical manipulator. Fig. 16 represents a microscopic joint of a Crinoid from the Upper Silurian of New Brunswick, injected with the hydrous silicate already referred to, and Fig. 17 shows a microscopic chambered or spiral shell, from a Welsh Silurian limestone, with its cavities filled with a similar substance.

Taking the specimens preserved by serpentine as typical, we now turn to certain other and, in some respects, less character-

istic specimens, which are nevertheless very instructive. At the Calumet some of the masses are partly filled with serpentine and partly with white pyroxene, an anhydrous silicate of lime and magnesia. The two minerals can readily be distinguished when viewed with polarized light; and in some slices I have seen part of a chamber or group of canals filled with



FIG. 18.—Casts of Canals of Eozoon in Serpentine, decalcified and highly magnified.



FIG. 19.—Canals of Eozoon. Highly Magnified.

serpentine and part with pyroxene. In this case the pyroxene, or the materials which now compose it, must have been introduced by infiltration, as well as the serpentine. This is the more remarkable as pyroxene is most usually found as an ingredient of igneous rocks; but Dr. Hunt has shown that in the Laurentian limestones, and also in veins traversing them, it

occurs under conditions which imply its deposition from water, either cold or warm. Gümbel remarks on this :—" Hunt, in a very ingenious manner, compares this formation and deposition of serpentine, pyroxene, and loganite, with that of glauconite, whose formation has gone on uninterruptedly from the Silurian to the Tertiary period, and is even now taking place in the depths of the sea; it being well known that Ehrenberg and others have already shown that many of the grains of glauconite are casts of the interior of foraminiferal shells. In the light of this comparison, the notion that the serpentine and such-like minerals of the primitive limestones have been formed, in a similar manner, in the chambers of Eozoic Foraminifera, loses any traces of improbability which it might at first seem to possess."

In many parts of the skeleton of Eozoon, and even in the best infiltrated serpentine specimens, there are portions of the cell wall and canal system which have been filled with calcareous spar or with dolomite, so similar to the skeleton that it can be detected only under the most favourable lights and with great care (Fig. 15, *supra*). It is further to be remarked that in all the specimens of true Eozoon, as well as in many other calcareous fossils preserved in ancient rocks, the calcareous matter, even when its minute structures are not preserved, or are obscured, presents a minutely granular or curdled appearance, arising, no doubt, from the original presence of organic matter, and not recognised in purely inorganic calcite.

Other specimens of fragmental Eozoon from the Petite Nation localities have their canals filled with dolomite, which probably penetrated them after they were broken up and imbedded in the rock. I have ascertained, with respect to these fragments of Eozoon, that they occur abundantly in certain layers of the Laurentian limestone, beds of some thickness being in great part made up of them, and coarse and fine frag-

ments occur in alternate layers, like the broken corals in some Silurian limestones.

Finally, on this part of the subject, careful observation of many specimens of Laurentian limestone which present no trace of Eozoon when viewed by the naked eye, and no evidence of structure when acted on with acids, are nevertheless organic, and consist of fragments of Eozoon, and possibly of other organisms, not infiltrated with silicates, but only with carbonate of lime, and consequently revealing only obscure indications of their minute structure. I have satisfied myself of this by long and patient investigations, which scarcely admit of any adequate representation, either by words or figures.

Every worker in those applications of the microscope to geological specimens which have been termed micro-geology, is familiar with the fact that crystalline forces and mechanical movements of material often play the most fantastic tricks with fossilized organic matter. In fossil woods, for example, we often have the tissues disorganized, with radiating crystallizations of calcite and little spherical concretions of quartz, or disseminated cubes and grains of pyrite, or little veins filled with sulphate of barium or other minerals. We need not, therefore, be surprised to find that in the venerable rocks containing Eozoon, such things occur in the highly crystalline Laurentian limestones, and even in some still showing the traces of Eozoon. We find many disseminated crystals of magnetite, pyrite, spinel, mica and other minerals, curiously curved prisms of vermicular mica, bundles of aciculi of tremolite and similar substances, veins of calcite and crysotile or fibrous serpentine, which often traverse the best specimens. Where these occur abundantly, we usually find no organic structures remaining, or if they exist, they are in a very defective state of preservation. Even in specimens presentingt he lamination of Eozoon to the naked eye, these crystalline actions have often destroyed the minute structure; and I fear that some microscopists have

been victimized, by having under their consideration only specimens in which the actual characters had been too much defaced to be discernible. No mistake can be greater than to suppose that any and every specimen of Laurentian limestone must contain Eozoon. More especially have I hitherto failed to detect traces of it in those carbonaceous or graphitic limestones which are so very abundant in the Laurentian country. Perhaps where vegetable matter was very plentiful Eozoon did not thrive, or, on the other hand, the growth of Eozoon may have diminished the quantity of vegetable matter. It is also to be observed that much compression and distortion have occurred in the beds of Laurentian limestone and their contained fossils, and also that the specimens are often broken by faults, some of which are so small as to appear only on microscopic examination, and to shift the plates of the fossil just as if they were beds of rock. This, though it sometimes produces puzzling appearances, is an evidence that the fossils were hard and brittle when this faulting took place, and is consequently an additional proof of their extraneous origin. In some specimens it would seem that the lower and older part of the fossil had been wholly converted into serpentine or pyroxene, or had so nearly experienced this change that only small parts of the calcareous wall can be recognised. These portions correspond with fossil woods altogether silicified, not only by the filling of the cells, but also by the conversion of the walls into silica. I have specimens which manifestly show the transition from the ordinary condition of filling with serpentine to one in which the cell-walls are represented obscurely by one shade of this mineral and the cavities by another. In general, however, it will be gathered from the above explanations that the specimens of Eozoon fall short in thoroughness of mineralization of some fossils in much more modern rocks. I have specimens of ancient sponges whose spicular skeletons, originally silicious, have been replaced by pyrite or bisulphide of iron, and of

Tertiary fossil woods retaining perfectly their most minute structures, yet entirely replaced by silica, so that not a particle of the original wood remains.

The above considerations as to mode of preservation of Eozoon concur with those in the previous chapter in showing its oceanic character, if really a fossil; but the ocean of the Eozoic period may not have been so deep as at present, and its waters were probably warm and well stocked with mineral matters derived from the newly formed land, or from hot springs in its own bottom. On this point the interesting investigations of Dr. Hunt with reference to the chemical conditions of the Silurian seas allow us to suppose that the Laurentian ocean may have been much more richly stored, more especially with salts of lime and magnesia, than that of subsequent times. Hence the conditions of warmth, light, and nutriment required by such gigantic Protozoans would all be present, and hence, also, no doubt, some of the peculiarities of their mineralization.

I desire by the above statement of facts to show, on the one hand, that the study of Eozoon, regarded as probably an ancient form of marine life, aids us in understanding other ancient fossils, and their manner of preservation; and on the other hand, that those who deny the organic origin of Eozoon place us in the position of being unable, in any rational manner, to account for these forms, so characteristic of the Laurentian limestones, and set at naught the fair conclusions deducible from the mode of preservation of fossils in the later formations. The evidence of organic origin is perhaps not conclusive, and in the present state of knowledge it is certain to be met with much scepticism, more especially by certain classes of specialists, whose grasp of knowledge is not sufficiently wide to cover, on the one hand, fossilization and metamorphism, and on the other, to understand the lower forms of life. It may, however, be sufficient to qualify us in turning our thoughts for a few moments to con-

siderations suggested by the probable origin of animal life in the seas of the Laurentian period.

Looking down from the elevation of our physiological and mental superiority, it is difficult to realize the exact conditions in which life exists in creatures so simple as the Protozoa. There may perhaps be higher intelligences, that find it equally difficult to realize how life and reason can manifest themselves in such poor houses of clay as those we inhabit. But placing ourselves near to these creatures, and entering, as it were, into sympathy with them, we can understand something of their powers and feelings. In the first place it is plain that they can vigorously, if roughly, exercise those mechanical, chemical, and vegetative powers of life which are characteristic of the animal. They can seize, swallow, digest, and assimilate food; and, employing its albuminous parts in nourishing their tissues, can burn away the rest in processes akin to our respiration, or reject it from their system. Like us, they can subsist only on food which the plant has previously produced; for in this world, from the beginning of time, the plant has been the only organism which could use the solar light and heat as forces to enable it to turn the dead elements of matter into living, growing tissues, and into organic compounds capable of nourishing the animal. Like us, the Protozoa expend the food which they have assimilated in the production of animal force, and in doing so cause it to be oxidized, or burnt away, and resolved again into dead matter. It is true that we have much more complicated apparatus for performing these functions, but it does not follow that these give us much real superiority, except relatively to the more difficult conditions of our existence. The gourmand who enjoys his dinner may have no more pleasure in the act than the Amœba which swallows a Diatom; and for all that the man knows of the subsequent processes to which the food is subjected, his interior might be a mass of jelly, with extemporised vacuoles,

like that of his humble fellow-animal. The clay is after all the same, and there may be as much difficulty in the making of a simple organism with varied powers, as a more complex frame for doing higher work.

In order that we may feel, a complicated apparatus of nerves and brain cells has to be constructed and set to work; but the Protozoon, without any distinct brain, is all brain, and its sensation is simply direct. Thus vision in these creatures is probably performed in a rough way by any part of their transparent bodies, and taste and smell are no doubt in the same case. Whether they have any perception of sound as distinct from the mere vibrations ascertained by touch, we do not know. Here, also, we are not far removed above the Protozoa, especially those of us to whom touch, seeing and hearing are direct acts, without any thought or knowledge of the apparatus employed. We might, so far, as well be Amœbas. As we rise higher we meet with more differences. Yet it is evident that our gelatinous fellow being can feel pain, dread danger, desire possessions, enjoy pleasure, and in a direct unconscious way entertain many of the appetites and passions that affect ourselves. The wonder is that with so little of organization it can do so much. Yet, perhaps, life can manifest itself in a broader and more intense way where there is little organization, and a highly strung and complex organism is not so much a necessary condition of a higher life as a mere means of better adapting it to its present surroundings.

A similar lesson is taught by the complexity of their skeletons. We speak in a crude, unscientific way of these animals accumulating calcareous matter, and building up reefs of limestone. We must, however, bear in mind that they are as dependent on their food for the materials of their skeletons as we are, and that their crusts grow in the interior of the sarcode just as our bones do within our bodies. The provision even for nourishing the interior of the skeleton by

tubuli and canals is in principle similar to that involved in the canals, cells, and canalicules of bone. The Amœba, of course, knows neither more nor less of this than the average Englishman. It is altogether a matter of unconscious growth. The process in the Protozoa strikes some minds, however, as the more wonderful of the two. It is, says an eminent modern physiologist, a matter of "profound significance" that this "particle of jelly [the sarcode of a Foraminifer] is capable of guiding physical forces in such a manner as to give rise to these exquisite and almost mathematically arranged structures." Respecting the structures themselves there is no exaggeration in this. No arch or dome framed by human skill is more perfect in beauty or in the realization of mechanical ideas than the tests of some Foraminifera, and none is so complete and wonderful in its internal structure. The particle of jelly, however, is a figure of speech. The body of the humblest Foraminifer is much more than this. It is an organism with divers parts, and it is endowed with the mysterious forces of life which in it guide the physical forces, just as they do in building up phosphate of lime in our bones, or indeed, just as the will of the architect does in building a palace. The profound significance which this has, reaches beyond the domain of the physical and vital, even to the spiritual. It clings to all our conceptions of living things: "quite as much, for example, to the evolution of an animal with all its parts from a one-celled germ, as to the connection of brain cells with the manifestations of intelligence." Viewed in this way, we may share with the author of the sentence I have quoted his feeling of veneration in the presence of this great wonder of animal life, "burning, and not consumed," nay, building up, and that in many and beautiful forms. We may realize it most of all in the presence of the organism which was perhaps the first to manifest on our planet these marvellous powers. We must, however, here also, beware of that credulity which makes too many

thinkers limit their conceptions altogether to physical force in matters of this kind. The merely materialistic physiologist is really in no better position than the savage who quails before the thunderstorm, or rejoices in the solar warmth, and seeing no force or power beyond, fancies himself in the immediate presence of his God. In Eozoon we must discern not only a mass of jelly but a being endowed with that higher vital force which surpasses vegetable life, and also physical and chemical forces; and in this animal energy we must see an emanation from a Will higher than our own, ruling vitality itself; and this not merely to the end of constructing the skeleton of a Protozoon, but of elaborating all the wonderful developments of life that were to follow in succeeding ages, and with reference to which the production and growth of this creature were initial steps. It is this mystery of design which really constitutes the "profound significance" of the foraminiferal skeleton.

Another phenomenon of animality forced upon our notice by the Protozoa is that of the conditions of life in animals not individual, as we are, but aggregative and cumulative in indefinite masses. What, for instance, the relations to each other of the Polyps, growing together in a coral mass, or the separate parts of a Sponge, or the separate lobes of a Foraminifer. In the case of the Polyps we may believe that there is special sensation in the tentacles and oral opening of each individual, and that each may experience hunger when in want, or satisfaction when it is filled with food, and that injuries to one part of the mass may indirectly affect other parts, but that the nutrition of the whole mass may be as much unfelt by the individual Polyps as the processes going on in our own liver are by us. So in the case of a large Sponge, or Foraminifer, there may be some special sensation in individual cells, pseudopods, or segments, and the general sensation may be very limited, while unconscious living powers pervade the

whole. In this matter of aggregation of animals we have thus various grades. The Foraminifers and Sponges present us with the simplest of all, and that which most resembles the aggregation of buds in the plant. The Polyps and complex Bryozoons present a higher and more specialized type; and though the bilateral symmetry which obtains in the higher animals is of a different nature, it still at least reminds us of that multiplication of similar parts which we see in the lower grades of being. It is worthy of notice here that the lower animals which show aggregative tendencies present but imperfect indications, or none at all, of bilateral symmetry. Their bodies, like those of plants, are for the most part built up around a central axis, or they show tendencies to spiral modes of growth.

It is this composite sort of life which is connected with the main geological function of the Foraminifer. While active sensation, appetite, and enjoyment pervade the pseudopods and external sarcode of the mass, the hard skeleton common to the whole is growing within; and in this way the calcareous matter is gradually removed from the sea water, and built up in solid reefs, or in piles of loose foraminiferal shells. Thus it is the aggregative or common life, alike in Foraminifers as in Corals, that tends most powerfully to the accumulation of calcareous matter; and those creatures whose life is of this complex character are best suited to be world builders, since the result of their growth is not merely a cemetery of their osseous remains, but a huge communistic edifice, to which multitudes of lives have contributed, and in which successive generations take up their abode on the remains of their ancestors. This process, so potent in the progress of the earth's geological history, began, as far as we know, with Eozoon.

Whether, then, in questioning our proto-foraminifer, we have reference to the vital functions of its gelatinous sarcode, to the complexity and beauty of its calcareous test, or to its capacity

for effecting great material results through the union of individuals, we perceive that we have to do, not with a low condition of those powers which we designate life, but with their manifestation through the means of a simple organism; and this in a degree of perfection which we, from our point of view, would have in the first instance supposed impossible.

If we imagine a world altogether destitute of life, we still might have geological formations in progress. Not only would volcanoes belch forth their liquid lavas and their stones and ashes, but the waves and currents of the ocean and the rains and streams on the land, with the ceaseless decomposing action of the carbonic acid of the atmosphere, would be piling up mud, sand, and pebbles in the sea. There might even be some formation of limestone taking place where springs charged with bicarbonate of lime were oozing out on the land or the bottom of the waters. But in such a world all the carbon would be in the state of carbon dioxide, and all the limestone would either be diffused in small quantities through various rocks or in limited local beds, or in solution, perhaps as chloride of calcium, in the sea. Dr. Hunt has given chemical grounds for supposing that the most ancient seas were largely supplied with this very soluble salt, instead of the chloride of sodium, or common salt, which now prevails in the sea water.

Where in such a world would life be introduced? on the land or in the waters? All scientific probability would say in the latter.[1] The ocean is now vastly more populous than the land. The waters alone afford the conditions necessary at once for the most minute and the grandest organisms, at once for the simplest and for others of the most complex character. Especially do they afford the best conditions for

[1] A recent writer (Simroth) has, however, undertaken to maintain the thesis that land life preceded that in the sea. It is unnecessary to say that he is an evolutionist, influenced by the necessity laid upon that philosophy to deduce whales, seals, etc., from land animals.

those animals which subsist in complex communities, and which aggregate large quantities of mineral matter in their skeletons. So true is this that up to the present time all the species of Protozoa and of the animals most nearly allied to them are aquatic. Even in the waters, however, plant life, though possibly in very simple forms, must precede the animal.

Let humble plants, then, be introduced in the waters, and they would at once begin to use the solar light for the purpose of decomposing carbonic acid, and forming carbon compounds which had not before existed, and which, independently of vegetable life, would never have existed. At the same time lime and other mineral substances present in the sea water would be fixed in the tissues of these plants, either in a minute state of division, as little grains or Coccoliths, or in more solid masses like those of the Corallines and Nullipores. In this way a beginning of limestone formation might be made, and quantities of carbonaceous and bituminous matter, resulting from the decay of vegetable substances might accumulate on the sea bottom. Now arises the opportunity for animal life. The plants have collected stores of organic matter, and their minute germs, along with microscopic species, are floating everywhere in the sea. The plant has fulfilled its function as far as the waters are concerned, and now a place is prepared for the animal. In what form shall it appear? Many of its higher forms, those which depend upon animal food or on the more complex plants for subsistence, would obviously be unsuitable. Further, the sea water is still too much saturated with saline matter to be fit for the higher animals of the waters. Still further, there may be a residue of internal heat forbidding coolness, and that solution of free oxygen which is an essential condition of existence to the higher forms of life. Something must be found suitable for this saline, imperfectly oxygenated, tepid sea. Something, too, is wanted that can aid in introduc-

ing conditions more favourable to higher life in the future. Our experience of the modern world shows us that all these conditions can be better fulfilled by the Protozoa than by any other creatures. They can live now equally in those great depths of ocean where the conditions are most unfavourable to other forms of life, and in tepid unhealthy pools overstocked with vegetable matter in a state of putridity. They form a most suitable basis for higher forms of life. They have remarkable powers of removing mineral matters from the waters and of fixing them in solid forms. So, in the fitness of things, a gigantic Foraminifer is just what we need, and after it has spread itself over the mud and rock of the primeval seas, and built up extensive reefs therein, other animals may be introduced, capable of feeding on it, or of sheltering themselves in its stony masses, and thus we have the appropriate dawn of animal life.

But what are we to say of the cause of this new series of facts, so wonderfully superimposed upon the merely vegetable and mineral? Must it remain to us as an act of creation, or was it derived from some pre-existing matter in which it had been potentially present? Science fails to inform us, but conjectural "phylogeny" steps in and takes its place. Haeckel, the prophet of this new philosophy, waves his magic wand, and simple masses of sarcode spring from inorganic matter, and form diffused sheets of sea slime, from which are in time separated distinct amœboid and foraminiferal forms. Experience, however, gives us no facts whereon to build this supposition, and it remains neither more nor less scientific or certain than that old fancy of the Egyptians, which derived animals from the fertile mud of the Nile.

If we fail to learn anything of the origin of Eozoon, and if its life processes are just as inscrutable as those of higher creatures, we can at least enquire as to its history in geological time. In this respect we find, in the first place, that

the Protozoa have not had a monopoly in their profession of accumulators of calcareous rock.

Originated by Eozoon in the old Laurentian time, this process has been proceeding throughout the geological ages; and while Protozoa, equally simple with the great prototype of the race, have been and are continuing its function, and producing new limestones in every geological period, and so adding to the volume of the successive formations, new workers of higher grades have been introduced, capable of enjoying higher forms of animal activity, and equally of labouring at the great task of continent building; of existing, too, in seas less rich in mineral substances than those of the Eozoic time, and for that very reason better suited to higher and more skilled artists. It is to be observed in connection with this, that as the work of the Foraminifers has thus been assumed by others, their size and importance have diminished, and the larger forms of more recent times have some of them been fain to build up their hard parts of cemented sand instead of limestone.

When the marvellous results of recent deep-sea dredgings were first made known, and it was found that chalky foraminiferal earth is yet accumulating in the Atlantic, with sponges and sea urchins, resembling in many respects those whose remains exist in the chalk, the fact was expressed by the statement that we still live in the chalk period. Thus stated the conclusion is scarcely correct. We do not live in the chalk period, but the conditions of the chalk period still exist in the deeper portions of the sea. We may say more than this. To some extent the conditions of the Laurentian period still exist in the sea, except in so far as they have been removed by the action of the Foraminifera and other limestone builders. To those who can realize the enormous lapse of time involved in the geological history of the earth, this conveys an impression almost of eternity in the existence of this oldest of all the families of the animal kingdom.

We are still more deeply impressed with this when we bring into view the great physical changes which have occurred since the dawn of life. When we consider that the skeletons of Eozoon contribute to form the oldest hills of our continents; that they have been sealed up in solid marble, and that they are associated with hard crystalline rocks contorted in the most fantastic manner; that these rocks have almost from the beginning of geological time been undergoing waste to supply the material of new formations; that they have witnessed innumerable subsidences and elevations of the continents; and that the greatest mountain chains of the earth have been built up from the sea since Eozoon began to exist,—we acquire a most profound impression of the persistence of the lower forms of animal life, and know that mountains may be removed and continents swept away and replaced, before the least of the humble gelatinous Protozoa can finally perish. Life may be a fleeting thing in the individual, but as handed down through successive generations of beings, and as a constant animating power in successive organisms, it appears, like its Creator, eternal.

This leads to another and very serious question. How long did lineal descendants of Eozoon exist, and do they still exist? We may for the present consider this question apart from ideas of derivation and elevation into higher planes of existence. Eozoon as a species, and even as a genus, may cease to exist with the Eozoic age, and we have no evidence whatever that any succeeding creatures are its modified descendants. As far as their structures inform us, they may as much claim to be original creations as Eozoon itself. Still descendants of Eozoon may have continued to exist, though we have not yet met with them. I should not be surprised to hear of a veritable specimen being some day dredged alive in the Atlantic or the Pacific. It is also to be observed that in animals so simple as this many varieties may appear, widely different from the

original. In these the general form and habit of life are the most likely things to change, the minute structures much less so. We need not, therefore, be surprised to find its descendants diminishing in size or altering in general form, while the characters of the fine tubulation and of the canal system would remain. We need not wonder if any sessile Foraminifer of the Nummuline group should prove to be a descendant of Eozoon. It would be less likely that a Sponge or a Foraminifer of the Rotaline type should originate from it. If one could only secure a succession of deep-sea limestones with Foraminifers extending all the way from the Laurentian to the present time, I can imagine nothing more interesting than to compare the whole series, with the view of ascertaining the limits of descent with variation, and the points where new forms are introduced. We have not yet such a series, but it may be obtained; and as these creatures are eminently cosmopolitan, occurring over vastly wide areas of sea bottom, and are very variable, they would afford a better test of theories of derivation than any that can be obtained from the more locally distributed and less variable animals of higher grade. I was much struck with this recently, in examining a series of Foraminifera from the Cretaceous of Manitoba, and comparing them with the varietal forms of the same species in the interior of Nebraska, 500 miles to the south, and with those of the English chalk and of the modern seas. In all these different times and places we had the same species. In all they existed under so many varietal forms passing into each other, that in former times every species had been multiplied by naturalists into several. Yet, in all, the identical varietal forms were repeated with the most minute markings the same. Here were at once constancy the most remarkable, and variations the most extensive. If we dwell on the one to the exclusion of the other, we reach only one-sided conclusions, imperfect and unsatisfactory. By taking both into connection we can alone realize the full significance

of the facts. We cannot yet obtain such series for all geological time; but it may even now be worth while to enquire, What do we know as to any modification in the case of the primeval Foraminifers, whether with reference to the derivation from them of other Protozoa or of higher forms of life?

There is no link in geological fact to connect Eozoon with any of the Mollusks, Radiates, or Crustaceans of the succeeding Cambrian. What may be discovered in the future we cannot conjecture; but at present these stand before us as distinct creations. It would of course be more probable that Eozoon should be the ancestor of some of the Foraminifera of the Primordial age, but strangely enough it is very dissimilar from all these, except Cryptozoum and some forms of Stromatopora; and here, as already stated, the evidence of minute structure fails to a great extent. Of actual facts, therefore, we have none; and those evolutionists who have regarded the dawn animal as an evidence in their favour have been obliged to have recourse to supposition and assumption.

We may imagine Eozoon itself, however, to state its experience as follows:—"I, Eozoon Canadense, being a creature of low organization and intelligence, and of practical turn, am no theorist, but have a lively appreciation of such facts as I am able to perceive. I found myself growing upon the sea bottom, and know not whence I came. I grew and flourished for ages, and found no let or hindrance to my expansion, and abundance of food was always floated to me without my having to go in search of it. At length a change came. Certain creatures with hard snouts and jaws began to prey on me. Whence they came I know not; I cannot think that they came from the germs which I had dispersed so abundantly throughout the ocean. Unfortunately, just at the same time lime became a little less abundant in the waters, perhaps because of the great demands I myself had made, and thus it was not so easy as before to produce a thick supplemental skeleton for defence.

So I had to give way. I have done my best to avoid extinction; but it is clear that I must at length be overcome, and must either disappear or subside into a humbler condition, and that other creatures better provided for the new conditions of the world must take my place." In such terms we may suppose that this patriarch of the seas might tell his history, and mourn his destiny, though he might also congratulate himself on having in an honest way done his duty and fulfilled his function in the world, leaving it to other and perhaps wiser creatures to dispute as to his origin and fate, while perhaps much less perfectly fulfilling the ends of their own existence.

Thus our dawn animal has positively no story to tell as to its own introduction or its transmutation into other forms of existence. It leaves the mystery of creation where it was, but in connection with the subsequent history of life we can learn from it a little as to the laws which have governed the succession of animals in geological time. First, we may learn that the plan of creation has been progressive, that there has been an advance from the few low and generalized types of the primæval ocean to the more numerous, higher, and more specialized types of more recent times. Secondly, we learn that the lower types, when first introduced, and before they were subordinated to higher forms of life, existed in some of their grandest modifications as to form and complexity, and that in succeeding ages, when higher types were replacing them, they were subjected to decay and degeneracy. Thirdly, we learn that while the species has a limited term of existence in geological time, any large type of animal existence, like that of the Foraminifera or Sponges, for example, once introduced, continues and finds throughout all the vicissitudes of the earth some appropriate residence. Fourthly, as to the mode of introduction of new types, or whether such creatures as Eozoon had any direct connection with the subsequent introduction of Mollusks, Worms, or Crustaceans, it is altogether silent, nor

can it predict anything as to the order or manner of their introduction.

Had we been permitted to visit the Laurentian seas, and to study Eozoon and its contemporary Protozoa when alive, it is plain that we could not have foreseen or predicted from the consideration of such organisms the future development of life. No amount of study of the prototypal Foraminifer could have led us distinctly to the conception of even a Sponge or a Polyp, much less of any of the higher animals. Why is this? The answer is that the improvement into such higher types does not take place by any change of the elementary sarcode, either in those chemical, mechanical, or vital properties which we can study, but in the adding to it of new structures. In the Sponge, which is perhaps the nearest type of all, we have the movable pulsating cilium and true animal cellular tissue, and along with this the spicular or fibrous skeleton, these structures leading to an entire change in the mode of life and subsistence. In the higher types of animals it is the same. Even in the highest we have white blood corpuscles and germinal matter, which, in so far as we know, carry on no higher forms of life than those of an Amœba; but they are now made subordinate to other kinds of tissues, of great variety and complexity, which never have been observed to arise out of the growth of any Protozoon. There would be only a few conceivable inferences which the highest finite intelligence could deduce as to the development of future and higher animals. He might infer that the Foraminiferal sarcode, once introduced, might be the substratum or foundation of other but unknown tissues in the higher animals, and that the Protozoon type might continue to subsist side by side with higher forms of living things, as they were successively introduced. He might also infer that the elevation of the animal kingdom would take place with reference to those new properties of sensation and voluntary motion in which the humblest animals diverge from the life of the plant

It is important that these points should be clearly before our minds, because there has been current of late among naturalists a loose way of writing with reference to them, which seems to have imposed on many who are not naturalists. It has been said, for example, that such an organism as Eozoon may include potentially all the structures and functions of the higher animals, and that it is possible that we might be able to infer or calculate all these with as much certainty as we can calculate an eclipse or any other physical phenomenon. Now, there is not only no foundation in fact for these assertions, but it is, from our present standpoint, not conceivable that they can ever be realized. The laws of inorganic matter give no data whence any *à priori* deductions or calculations could be made as to the structure and vital forces of the plant. The plant gives no data from which we can calculate the functions of the animal. The Protozoon gives no data from which we can calculate the specialties of the Mollusk, the Articulate, or the Vertebrate. Nor, unhappily, do the present conditions of life of themselves give us any sure grounds for predicting the new creations that may be in store for our old planet. Those who think to build a philosophy and even a religion on such data are mere dreamers, and have no scientific basis for their dogmas. They are as blind guides as our primæval Protozoon himself would be in matters whose real solution lies in the harmony of our own higher and immaterial nature with the Being who is the Author of all life—the Father "from whom every family in heaven and earth is named."

REFERENCES :—"Life's Dawn on Earth." London, 1885. Specimens of Eozoon in the Peter Redpath Museum, Montreal, 1888.

THE APPARITION AND SUCCESSION OF ANIMAL FORMS.

DEDICATED TO THE MEMORY OF

THE EMINENT SWISS AND AMERICAN ZOOLOGIST

LOUIS AGASSIZ,

THE FOUNDER OF THE MODERN SCHOOL OF AMERICAN BIOLOGY,

AND OF

SIR RICHARD OWEN,

A GREAT AND PHILOSOPHICAL NATURALIST,

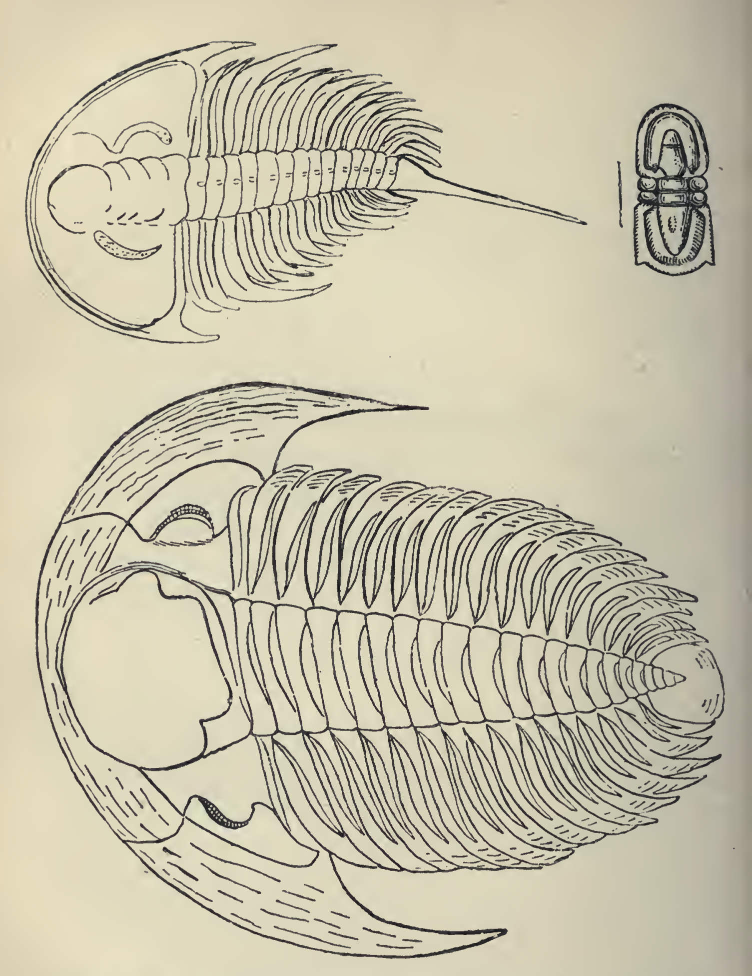
TO WHOSE TEACHING I AND VERY MANY OTHERS OWE OUR EARLIEST

INTRODUCTION TO THE PRINCIPLE OF HOMOLOGY

IN THE ANIMAL KINGDOM.

Modern Ideas of Derivation—Development of Animal Forms in Time—Various Theories of Derivation—History of Organic Types—History of Organs—Testimony of the Geological Record—Laws of the Succession—Development and Evolution—Evolutionist Theologians





Old forms of Trilobites, from the Lower Cambrian (p. 173 *et seq.*)
Olenellus Thompsoni, Emmons.
Agnostus vir, Matthew.
Paradoxides regina, Matthew.

CHAPTER VII.

THE APPARITION AND SUCCESSION OF ANIMAL FORMS.

TIME was when naturalists were content to take nature as they found it, without any over-curious inquiries as to the origin of its several parts, or the changes of which they might be susceptible. Geology first removed this pleasant state of repose, by showing that all our present species had a beginning, and were preceded by others, and these again by others. Geologists were, however, too much occupied with the facts of the succession to speculate on the ultimate causes of the appearance and disappearance of species, and it remained for zoologists and botanists, or as some prefer to call themselves, biologists, to construct hypotheses or theories to account for the ascertained fact that successive dynasties of species have succeeded each other in time. I do not propose in this paper so much to deal with the various doctrines as to derivation and development now current, as to ask the question, What do we actually know as to the origin and history of life on our planet?

This great question, confessedly accompanied with many difficulties and still waiting for its full solution, has points of intense interest both for the Geologist and the Biologist. "If," says the great founder of the uniformitarian School of Geology, "the past duration of the earth be finite, then the aggregate of geological epochs, however numerous, must constitute a mere moment of the past, a mere infinitesimal portion of eternity." Yet to our limited vision, the origin of life fades

away in the almost illimitable depths of past time, and we are ready to despair of ever reaching, by any process of discovery, to its first steps of progress. At what time did life begin? In what form did dead matter first assume or receive those mysterious functions of growth, reproduction and sensation? Only when we picture to ourselves an absolutely lifeless world, destitute of any germ of life or organization, can we realize the magnitude of these questions, and perceive how necessary it is to limit their scope if we would hope for any satisfactory answer.

We may here dismiss altogether that form in which these questions present themselves to the biologist, when he experiments as to the evolution of living forms from dead liquids or solids attacking the unsolved problem of spontaneous generation. Nor need we enter on the vast field of discussion as to modern animals and plants opened up by Darwin and others. I shall confine myself altogether to that historical or palæontological aspect in which life presents itself when we study the fossil remains entombed in the sediments of the earth's crust, and which will enable me at least to show why some students of fossils hesitate to give in their adhesion to any of the current notions as to the origin of species. It will also be desirable to avoid, as far as possible, the use of the term "evolution," as this has recently been employed in so many senses, whether of development or causation, as to have become nearly useless for any scientific purpose; and that when I speak of creation of species, the term is to be understood not in the arbitrary sense forced on it by some modern writers, but as indicating the continuous introduction of new forms of life under definite laws, but by a power not emanating from within themselves, nor from the inanimate nature surrounding them.[1]

[1] The terms Derivation, Development and Causation have clear and definite meanings, and it is preferable, wherever possible, to use one or other of these.

If we were to follow the guidance of those curious analogies which present themselves when we consider the growth of the individual plant or animal from the spore or the ovum, and the development of vegetable and animal life in geological time—analogies which, however, it must be borne in mind can have no scientific value whatever, inasmuch as that similarity of conditions which alone can give force to reasoning from analogy in matters of science, is wholly wanting—we should expect to find in the oldest rocks embryonic forms alone, but of course embryonic forms suited to exist and reproduce themselves independently.[1]

I need not say to palæontologists that this is not what we actually find in the primordial rocks. I need but to remind them of the early and remarkable development of such forms as the Trilobites, the Lingulidæ and the Pteropods, all of them highly complex and specialized types, and remote from the embryonic stages of the groups to which they severally belong. In the case of the Trilobites, one need merely consider the beautiful symmetry of their parts, both transversely and longitudinally, their division into distinct regions, the necessary complexity of their muscular and nervous systems, their highly complex visual organs, the superficial ornamentation and microscopic structure of their crusts, their advanced position among Crustaceans, indicated by their strong affinity with the Arachnidans or spiders and scorpions. (See figures prefixed.)

[1] I may be pardoned for taking an example of the confusion of thought which this mode of reasoning has introduced into Biology from a clever article in the *Contemporary* written by a very able and much-esteemed biologist. He says: "The morphological distance between a newly hatched frog's tadpole and the adult frog is almost as great as that between the adult lancelet and the newly hatched larvæ of the lamprey." The "morphological distance" truly, but what of the physiological distance between the young and adult of the same animal and two adult animals between which is placed the great gulf of specific and generic diversity which within human experience neither has been known to pass?

All these characters give them an aspect far from embryonic, while, as Barrande has pointed out, this advanced position of the group has its significance greatly strengthened by the fact that in early primordial times we have to deal not with one species, but with a vast and highly differentiated group, embracing forms of many and varied subordinate types. As we shall see, these and other early animals may be regarded as of generalized types, but not as embryonic. Here, then, meets us at the outset the fact that in as far as the great groups of annulose and molluscous animals are concerned, we can trace these back no farther than to a period in which they appear already highly advanced, much specialized and represented by many diverse forms. Either, therefore, these great groups came in on this high initial plane, or we have scarcely reached half way back in the life-history of our planet.

We have, here, however, by this one consideration, attained at once to two great and dominant laws regulating the history of life. First, the law of continuity, whereby new forms come in successively, throughout geological time, though, as we shall see, with periods of greater or less frequency. Secondly, the law of specialization of types, whereby generalized forms are succeeded by those more special, and this probably connected with the growing specialization of the inorganic world. It is this second law which causes the parallelism between the history of successive species and that of the embryo.

We have already considered the claims which Eozoon and its contemporaries may urge to recognition, as beginnings of life; but when we ascend from the Laurentian beds, we find ourselves in a barren series of conglomerates, sandstones, and other rocks, indicating shore rather than sea conditions, and remarkably destitute of indications of life. These are the Huronian beds, and possibly other series associated with them. They have afforded spicules of sponges, casts of burrows of

worms, obscure forms, which may represent crustaceans or mollusks, markings of unknown origin, and some laminated forms which may perhaps represent remains of Eozoon, though their structures are imperfectly preserved. These are sufficient to show that marine life continued in some forms, and to encourage the hope that a rich pre-Cambrian fauna may yet be discovered.

But let us leave for the present the somewhat isolated case of Eozoon, and the few scattered forms of the Huronian, and go on farther to the early Cambrian fauna. This is graphically presented to us in the sections in South Wales, as described by Hicks. Here we find a nucleus of ancient rocks, supposed to be Laurentian, though in mineral character more nearly akin to the Huronian, but which have hitherto afforded no trace of fossils. Resting unconformably on these is a series of slates and sandstones, regarded as Lower Cambrian, the Caerfai group of Hicks, and which are the earliest holding organic remains. The lowest bed which contains indications of life is a red shale near the base of the series, which holds a few organic remains. The species are a *Lingulella*, worm burrows and a Trilobite.[1] Supposing these to be all, it is remarkable that we have no Protozoa or Corals or Echinoderms, and that the types of Brachiopods and Crustaceans are of comparatively modern affinities. Passing upward through 1,000 feet of barren sandstone and shale, we reach a zone in which many Trilobites of at least five genera are found, along with Pteropods, Brachiopods and Sponges. Thus it is that life comes in at the base of the Cambrian in Wales, and it may be regarded as a fair specimen of the facts as they appear in the earlier fossiliferous beds succeeding the Laurentian. Taking the first of these groups of fossils, we may recognise in the worms representatives of those that still haunt our shores, in the Trilobite a Crustacean or Arachnoid of no mean grade.

[1] Probably of the genus Olenellus.

The *Lingulellæ*, whether we regard them as molluscoids, or, with Professor Morse, as singularly specialized worms, represent a peculiar and distinct type, handed down, through all the vicissitudes of the geological ages, to the present day. Had the Primordial life begun with species altogether inscrutable and unexampled in succeeding ages, this would no doubt have been mysterious; but next to this is the mystery of the oldest forms of life being also among the newest. One great fact shines here with the clearness of noon-day. Whatever the origin of these creatures, they represent families which have endured till now in the struggle for existence without either elevation or degradation. Here, again, we may formulate another creative law. In every great group there are some forms much more capable of long continuance than others. Lingula among the Brachiopods is a marked instance.

But when, with Hicks, we surmount the mass of barren beds underlying these remains, which from its unfossiliferous character is probably a somewhat rapid deposit of Arctic mud, like that which in all geological time has constituted the rough filling of our continental formations, and have suddenly sprung upon us many genera of Trilobites, including the fewest-jointed and most many-jointed, the smallest and the largest of their race, our astonishment must increase, till we recognise the fact that we are now in the presence of another great law of creation, which provides that every new type shall be rapidly extended to the extreme limits of its power of adaptation.

That this is not merely local is evidenced by the researches of Matthew and Walcott in the oldest Cambrian of America, where a similar succession occurs, but with this difference, that in the wider area presented by the American continent we find a greater variety of forms of life. Walcott records up to 1892 no less than 67 genera and 165 species in the oldest Cambrian of America. These include representatives of the Sponges, Hydroids, Corals, Echinoderms, Worms, Brachiopods, Bivalve

and Univalve Mollusks and Crustaceans, or in other words, all the leading groups of invertebrate animals that we find in the sea at present. Of these the dominant group is the Crustaceans, including Trilobites, numbering one-third of the whole; and these with the univalve Mollusks and the Brachiopods constitute the majority, the other groups having comparatively few species. What a marvellous incoming of life is here! Walcott may well say that on the theory of gradual development we must suppose that life existed at a period far before the Cambrian—as far, indeed, as the Cambrian is before our own time. But this would mean that we know only half of the history of life; and perhaps it is more reasonable to suppose that when the conditions became favourable, it came in with a rush.

Before considering the other laws that may be inferred from these facts, however, let us in imagination transfer ourselves back to the Primordial age, and suppose that we have in our hands a living specimen of one of the larger Trilobites, recently taken from the sea, flapping vigorously its great tail, and full of life and energy; an animal larger and heavier than the modern king-crab of our shores, furnished with all the complexity of external parts for which the crustaceans are so remarkable, and no doubt with instincts and feelings and modes of action as pronounced as those of its modern allies, and, if Woodward's views are correct, on a higher plane of rank than the king-crab itself, inasmuch as it is a composite type connecting Limuli with Isopods, and even with scorpions. We have obviously here, in the appearance of this great Crustacean or Arachnoid, a repetition of the facts which we met with in Eozoon; but how vast the interval between them in geological time, and in zoological rank! Standing in the presence of this testimony, I think it is only right to say that we possess no causal solution of the appearance of these early forms of life; but in tracing them and their successors upward through the succeeding ages, we may hope at least to reach some expressions of the laws of

their succession, in possession of which we may return to attack the mystery of their origin.

First, it must strike every observer that there is a great sameness of plan throughout the whole history of marine invertebrate life. If we turn over the pages of an illustrated textbook of geology, or examine the cases or drawers of a collection of fossils, we shall find extending through every succeeding formation, representative forms of Crustaceans, Mollusks, Corals, etc., in such a manner as to indicate that in each successive period there has been a reproduction of the same type with modifications; and if the series is not continuous, this appears to be due rather to abrupt physical changes; since sometimes, where two formations pass into each other, we find a gradual change in the fossils by the dropping out and introduction of species one by one. Thus, in the whole of the great Palæozoic Period, both in its Fauna and Flora, we have a continuity and similarity of a most marked character.

It is evident that there is presented to us in this similarity of the forms of successive faunas and floras, a phenomenon which deserves very careful sifting as to the question of identity or diversity of species. The data for its comprehension must be obtained by careful study of the series of closely allied forms occurring in successive formations, and the great and undisturbed areas of the older rocks in America seem to give special facilities for this, which should be worked, not in the direction of constituting new species for every slightly divergent form, but in striving to group these forms into large specific types.[1]

There is nothing to preclude the supposition that some of the groups mentioned in the note are really specific types, with

[1] The Rynchonellæ of the type of *R. plena*, the Orthids, of the type of *O. testudinaria*, the Strophomenæ of the types of *S. alternata* and *S. Rhomboidalis*, the Atrypæ of the type of *A. reticularis*, furnish cases in point among the Brachiopods.

numerous race modifications. My own provisional conclusion, based on the study of Palæozoic plants, is that the general law will be found to be the existence of distinct specific types, independent of each other, but liable in geological time to a great many modifications, which have often been regarded as distinct species.[1]

While this unity of successive faunæ at first sight presents an appearance of hereditary succession, it loses much of this character when we consider the number of new types introduced without apparent predecessors, the necessity that there should be similarity of type in successive faunæ on any hypothesis of a continuous plan; and above all, the fact that the recurrence of representative species or races in large proportion marks times of decadence rather than of expansion in the types to which they belong. To turn to another period, this is very manifest in that singular resemblance which obtains between the modern mammals of South America and Australia, and their immediate fossil predecessors—the phenomenon being here manifestly that of decadence of large and abundant species into a few depauperated representatives. This will be found to be a very general law, elevation being accompanied by the apparent abrupt appearance of new types and decadence by the apparent continuation of old species, or modifications of them.

This resemblance with difference in successive faunas also connects itself very directly with the successive elevations and depressions of our continental plateaus in geological time. Every great Palæozoic limestone, for example, indicates a depression with succeeding elevation. On each elevation marine animals were driven back into the ocean, and on each depression swarmed in over the land, reinforced by new species, either then introduced, or derived by migration from other localities. In like manner, on every depression, land

[1] "Geological History of Plants."

plants and animals were driven in upon insular areas, and on re-elevation, again spread themselves widely. Now I think it will be found to be a law here that periods of expansion were eminently those of introduction of new specific types, and periods of contraction those of extinction, and also of continuance of old types under new varietal forms.

It must also be noticed that all the leading types of invertebrate life were early introduced, that change within these was necessarily limited, and that elevation could take place mainly by the introduction of the vertebrate orders. So in plants, Cryptogams early attained their maximum as well as Gymnosperms, and elevation occurred in the introduction of Phænogams, and this not piecemeal, but as we shall see in a succeeding chapter, in great force at once.

We may further remark the simultaneous appearance of like types of life in one and the same geological period, over widely separated regions of the earth's surface. This strikes us especially in the comparatively simple and homogeneous life-dynasties of the Palæozoic, when, for example, we find the same types of Silurian Graptolites, Trilobites and Brachiopods appearing simultaneously in Australia, America and Europe. Perhaps in no department is it more impressive than in the introduction of the Devonian and Carboniferous Ages of that grand cryptogamous and gymnospermous flora which ranges from Brazil to Spitzbergen, and from Australia to Scotland, accompanied in all by the same groups of marine invertebrates. Such facts may depend either on that long life of specific types which gives them ample time to spread to all possible habitats, before their extinction, or on some general law whereby the conditions suitable to similar types of life emerge at one time in all parts of the world. Both causes may be influential, as the one does not exclude the other, and there is reason to believe that both are natural facts. Should it be ultimately proved that species allied and representative, but distinct in

origin, come into being simultaneously everywhere, we shall arrive at one of the laws of creation, and one probably connected with the gradual change of the physical conditions of the world.

Another general truth, obvious from the facts which have been already collected, is the periodicity of introduction of species. They come in by bursts or flood tides at particular points of time, while these great life waves are followed and preceded by times of ebb in which little that is new is being produced. We labour in our investigation of this matter under the disadvantage that the modern period is evidently one of the times of pause in the creative work. Had our time been that of the early Tertiary or early Mesozoic, our views as to the question of origin of species might have been very different. It is a striking fact, in illustration of this, that since the glacial age no new species of mammal, except, possibly, man himself, can be proved to have originated on our continents, while a great number of large and conspicuous forms have disappeared. It is possible that the proximate or secondary causes of the ebb and flow of life production may be in part at least physical, but other and more important efficient causes may be behind these. In any case these undulations in the history of life are in harmony with much that we see in other departments of nature.

It results from the above and the immediately preceding statement, that specific and generic types enter on the stage in great force, and gradually taper off towards extinction. They should so appear in the geological diagrams made to illustrate the succession of living beings. This applies even to those forms of life which come in with fewest species and under the most humble guise. What a remarkable swarming, for example, there must have been of Marsupial Mammals in the early Mesozoic, and in the Coal formation the only known Pulmonate snails, five or six in number, belong to four generic

types, while the Myriapods and Amphibians alike appear in a crowd of generic forms.

I have already referred to the permanence of species in geological time. We may now place this in connection with the law of rapid origination and more or less continuous transmission of varietal forms. A good illustration will be afforded by a group of species with which I am very familiar, that which came into our seas at the beginning of the Glacial age, and still exists. With regard to their permanence, it can be affirmed that the shells now elevated in Wales to 1,200, and in Canada to 600 feet above the sea, and which lived before the last great revolution of our continents—a period very remote as compared with human history—differ in no tittle from their modern successors after hundreds or thousands of generations. It can also be affirmed that the more variable species appear under precisely the same varietal forms then as now, though these varieties have changed much in their local distribution. The real import of these statements, which might also be made with regard to other groups, well known to palæontologists, is of so great significance that it can be realized only after we have thought of the vast time and numerous changes through which these humble creatures have survived. I may call in evidence here a familiar New England animal, the common sand clam, *Mya arenaria*, and its relative *Mya truncata*, the short sand clam, which now inhabit together all the northern seas; for the Pacific specimens, from Japan and California, though differently named, are undoubtedly the same. *Mya truncata* appears in Europe in the Coralline Crag, and was followed by *M. arenaria* in the Red Crag. Both shells occur in the Pleistocene of America, and their several varietal forms had already developed themselves in the Crag, and remain the same to-day; so that these humble mollusks, littoral in their habits, and subjected to a great variety of conditions, have continued for a very long period to construct their shells

precisely as at present; while in many places, as on the Lower St. Lawrence, we find them living together on the same banks, and yet preserving their distinctness.[1] Nor are there any indications of a transition between the two species. I might make similar statements with regard to the Astartes, Buccinums and Tellinæ of the drift, and could illustrate them by extensive series of specimens from my own collections.

Another curious illustration is that presented by the Tertiary and modern faunæ of some oceanic islands far separated from the continents. In Madeira and Porto Santo, for example, according to Lyell, we have fifty-six species of land shells in the former, and forty-two in the latter, only twelve being common to the two, though these islands are only thirty miles apart. Now in the Pliocene strata of Madeira and Porto Santo we find thirty six species in the former, and thirty-five in the latter, of which only eight per cent. are extinct, and yet only eight are common to the two islands. Further, there seem to be no transitional forms connecting the species, and of some of them the same varieties existed in the Pliocene as now. The main difference in time is the extinction of some species and the introduction of others without known connecting links, and the fact that some species, plentiful in the Pliocene, are rare now, and *vice versâ*. All these shells differ from those of modern Europe, but some of them are allied to Miocene species of that continent. Here we have a case of continued existence of the same forms, and in circumstances which, the more we think of them, the more do they defy all our existing theories as to specific origins.

Perhaps some of the most remarkable facts in connection with the permanence of varietal forms of species are those furnished by that magnificent flora which burst in all its majesty on the American continent in the Cretaceous period, and still survives among us, even in some of its specific types.

[1] Paper in *Record of Science*, on Shells at Little Metis.

I say survives; for we have but a remnant of its forms living, and comparatively little that is new has probably been added since. The confusion which has obtained as to the age of this flora, and its mistaken reference to the Miocene Tertiary, have arisen in part from the fact that this modern flora was in its earlier times contemporary with Cretaceous animals, and survived the gradual change from the animal life of the Cretaceous down to that of the Eocene, and even of the Miocene. In collections of these plants, from what may be termed beds of transition from the Cretaceous to the Tertiary, we find many plants of modern species, or so closely related that they may be mere varietal forms. Some of these will be mentioned in the next paper, and they show that modern plants, some of them small and insignificant, others of gigantic size, reach back to a time when the Mesozoic Dinosaurs were becoming extinct, and the earliest Placental mammals being introduced. Shall we say that these plants have propagated themselves unchanged for half a million of years, or more?[1]

Take from the western Mesozoic a contrasting yet illustrative fact. In the lowest Cretaceous rocks of Queen Charlotte's Island, Mr. Richardson and Dr. G. M. Dawson find Ammonites and allied Cephalopods similar in many respects to those discovered farther south by the California Survey, and Mr. Whiteaves finds that some of them are apparently not distinct from species described by the Palæontologists of the Geological Survey of British India. On both sides of the Pacific these shells lie entombed in solid rock, and the Pacific rolls between, as of yore. Yet these species, genera, and even families are all extinct—why, no man can tell, while land plants that must have come in while the survivors of these Cephalopods still lived, reach down to the present. How mysterious is all this,

[1] Among these are living species of ferns, one of them our common "Sensitive Fern," of Eastern America, two species of Hazel still extant, and Sequoias or giant pines, like those now surviving in California.

and how strongly does it show the independence in some sense of merely physical agencies on the part of the manifestations of life!

We have naturally been occupied hitherto with the lower tribes of animals and with plant life, because these are predominant in the early ages of the earth. Let us turn now to the history of vertebrate or back-boned animals, which presents some peculiarities special to itself. Many years ago Pander[1] described and figured from the Cambro-silurian of Russia, a number of minute teeth, some conical and some comb-like, which he referred to fishes, and to that low form of the fish type represented by the modern lampreys. Much doubt was thrown on this determination, more especially as the teeth seemed to be composed not of bone earth, but of carbonate of lime, and it was suggested that they may have belonged to marine worms, or to the lingual ribbons of Gastropod mollusks. Some confirmatory evidence seems to have been supplied by the discovery of great numbers of similar forms in the shales of the coal formation of Ohio, by the late Dr. Newberry. I have had an opportunity to examine these, and find that they consist of calcium phosphate,[2] or bone earth, and that their microscopic structure is not dissimilar from that of the teeth of some of the smaller sharks (Diplodus) found with them. I have therefore been inclined to believe that there may have already been, even in the Cambrian or Lower Silurian seas, true fishes, related partly to the lampreys and partly to sharks; so that the history of the back-boned animals may have gone nearly as far back as that of their humbler relations. This conjecture has recently received further support from the discovery in rocks of Lower Silurian age, in Colorada of a veritable bone bed, rich in fragmentary remains of fishes.

[1] More recently Rohan has described conical teeth (St. Petersburg Academy, 1889), but I have not seen his paper.

[2] Analysis of Dr. B. J. Harrington.

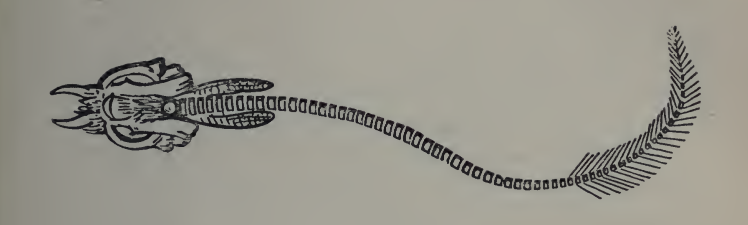
They are unfortunately so comminuted as to resemble the *débris* of the food of some larger animal; but in so far as I can judge from specimens kindly given to me,[1] they resemble the bony coverings of some of the familiar fishes of the Devonian. Thus they would indicate, with Pander's and Rohan's specimens, already two distinct types of fishes as existing almost as early as the higher invertebrates of the sea.

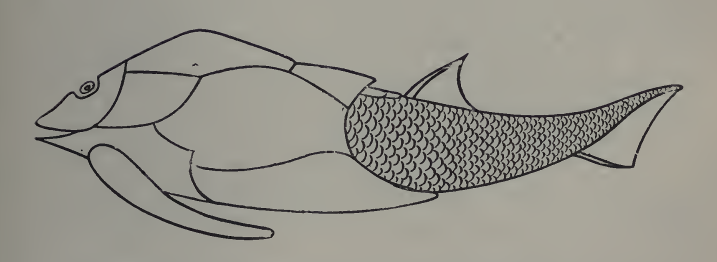
In the Silurian (Upper Silurian of Murchison) we have undoubted evidence of the same kind, on both sides of the Atlantic, in teeth and spines of sharks, and the plates which protected the heads and bodies of the plate-covered fishes (Placo-ganoids). But it is in the Devonian that these types appear to culminate, and we have added to them that remarkable type of "lung fish," as the Germans call them, represented in our modern world only by the curious and exceptional Burramunda of Australia, and the mud fishes of Africa and South America,[2] creatures which show, as do some of the mailed fishes, or ganoids, of equally great age, the intermediate stages between a swimming bladder and a lung, and thus approach nearer to the air-breathing animals than any other fishes.

Many years ago, in "Acadian Geology," I referred to the probability that the mailed and lung fishes of the Devonian and Carboniferous possessed airb ladders so constructed as to enable them to breathe air, as is the case with their modern representatives. In the modern species this, no doubt, enables them to haunt badly aërated waters, in swamps and sluggish streams, and in some cases even to survive when the water in which they live is dried up. In the Carboniferous and Devonian it may have served a similar purpose, fitting them to inhabit the lagoons and creeks of the coal swamps, the water of which must often have been badly aërated. It makes against this that some sharks followed them into these waters,

[1] By Mr. F. D. Adams and Dr. Walcott.

[2] Ceratodus, Lipidosiren, Protopterus.





Two Primitive Vertebrates, *Palæospondylus* (enlarged) and *Pterichthys* (reduced),
(After Woodward, with some modifications.)



and the modern sharks have no swim-bladders. Possibly, however, the sharks habitually haunted the open sea, and only made occasional raids on the dangerous waters tenanted by the ganoids. It is also true that only certain genera of sharks are found to be represented in the carbonaceous shales, and they may have differed in this respect from the ordinary forms of the order. It has been suggested that only a small change would be necessary to enable some of these lung fishes to become Batrachians, and no doubt this is the nearest approach of the fish to the reptile; but we have not yet found connecting links sufficient to bridge over the whole distance.

The plate-bearing ganoids of the Silurian and Devonian, at one time supposed to be allied to Crustaceans, but whose dignity as "Forerunners of the back-boned animals" is now generally admitted,[1] are clearly true fishes, and of somewhat high rank, their strange bony armour being evidently a special protection against the attacks of contemporary sharks and gigantic crustaceans; and if we may judge by the Colorado specimens, their existence dates back almost to the close of the Cambrian, and they were probably contemporary with small sharks; while as early as the Silurian and Devonian, if we regard the scaly ganoids as a distinct type, we have already four types of fishes, and these akin to those which in modern time we must regard as the highest of their class.

One very little fish of the Devonian, of which specimens have been kindly sent me by a friend in Scotland,[2] the Palæo-

[1] A. Smith Woodward, "Natural Science," 1892, and *Annals and Maga. Nat. Hist.*, October, 1890. This able naturalist, in introducing his subject, remarks, from the point of view of an evolutionist:—"Whether some form of 'worm' gave origin to the forerunners of the great back-boned race, or whether a primeval relative of the King-crab turned upside down and rearranged limbs and head—these are questions still admitting of endless discussion, no doubt fruitless in their main object, but desirable from the new lines of investigation they continually suggest."

[2] James Reed, Esq., of Allan House, Blairgowrie.

spondylus of Traquair, may raise still higher hopes for the early vertebrates. It is a little creature, an inch to two inches in length, destitute or nearly destitute of bony covering, having a head which suggests the presence of external gills, large eyes, and even elongated nasal bones,[1] a long vertebral column composed of separate bony rings, more than fifty in number, with possible indications of ribs in front and distinct neural and haemal processes behind. One cannot look at it without the suggestion occurring of some of the smaller snake-like Batrachians of the Carboniferous and Permian; and I should not be surprised if it should come to be regarded either as a forerunner of the Batrachians or as a primitive tadpole.

However this may be, the upper part of the Devonian, though rich in fishes and plants, has afforded no higher vertebrates than its lower parts, and in the lowest Carboniferous beds we suddenly find ourselves in the presence of Batrachians with well-developed limbs and characters which ally them to the Lizards. True lizard-like reptiles appear in the Permian, and then we enter on that marvellous reign of reptiles, in which this class assumed so many great and remarkable forms, and asserted itself in a manner of which the now degraded reptilian class can afford no conception.

The mammals and birds make their first appearance quietly in small and humble forms in the reign of reptiles, in which there was little place left for them by the latter; but the mammals burst upon us in all their number and magnitude in the Eocene and Miocene, in which quadrupedal mammalian life may be said to have culminated in grandeur, variety, and geographical distribution; far excelling in these respects the time in which we live.

The development in time of the back-boned animals thus stands in some degree by itself; but it illustrates the same

[1] I am aware that Woodward regards these parts differently.

laws of early generalised types, and sudden and wide introduction of new forms, which we have seen in the case of the invertebrates and the plants.

Such facts as those to which I have referred, and many others, which want of space prevents me from noticing, are in one respect eminently unsatisfactory, for they show us how difficult must be any attempts to explain the origin and succession of life. For this reason they are quietly put aside or explained away in most of the current hypotheses on the subject. But we must, as men of science, face these difficulties, and be content to search for facts and laws, even if they should prove fatal to preconceived views.

A group of new laws, indeed, here breaks upon us. (1) The great vitality and rapid extension and variation of new specific types. (2) The law of spontaneous decay and mortality of species in time. (3) The law of periodicity and of simultaneous appearance of many allied forms. (4) The abrupt entrance and slow decay of groups of species. (5) The extremely long duration of some species in time. (6) The grand march of new forms landwards, and upwards in rank. Such general truths deeply impress us at least with the conclusion that we are tracing, not a fortuitous succession, but the action of power working by law.

I have thus far said nothing of the bearing of the prevalent ideas of descent with modification on this wonderful procession of life. None of these, of course, can be expected to take us back to the origin of living beings; but they also fail to explain why so vast numbers of highly organized species struggle into existence simultaneously in one age and disappear in another, why no continuous chain of succession in time can be found gradually blending species into each other, and why, in the natural succession of things, degradation under the influence of external conditions and final extinction seem to be laws of organic existence. It is useless here to appeal to the

imperfection of the record, or to the movements or migrations of species. The record is now, in many important parts, too complete, and the simultaneousness of the entrance of the faunas and floras too certainly established, and moving species from place to place only evades the difficulty. The truth is that such hypotheses are at present premature, and that we require to have larger collections of facts. Independently of this, however, it appears to me that from a philosophical point of view it is extremely probable that all theories of evolution, as at present applied to life, are fundamentally defective in being too partial in their character; and perhaps I cannot better group the remainder of the facts to which I wish to refer than by using them to illustrate this feature of most of our attempts at generalization on this subject.

First, then, these hypotheses are too partial, in their tendency to refer numerous and complex phenomena to one cause, or to a few causes only, when all trustworthy analogy would indicate that they must result from many concurrent forces and determinations of force. We have all, no doubt, read those ingenious, not to say amusing, speculations in which some entomologists and botanists have indulged with reference to the mutual relations of flowers and suctorial insects. Geologically the facts oblige us to begin with Cryptogamous plants and chewing insects, and out of the desire of insects for non-existent honey, and the adaptations of plants to the requirements of non-existent suctorial apparatus, we have to evolve the marvellous complexity of floral form and colouring, and the exquisitely delicate apparatus of the mouths of haustellate insects. Now, when it is borne in mind that this theory implies a mental confusion on our part precisely similar to that which, in the department of mechanics, actuates the seekers for perpetual motion, that we have not the smallest tittle of evidence that the changes required have actually occurred in any one case, and that the thousands of other structures and relations of the plant and the

insect have to be worked out by a series of concurrent developments so complex and absolutely incalculable in the aggregate, that the cycles and epicycles of the Ptolemaic astronomy were child's play in comparison, we need not wonder that the common sense of mankind revolts against such fancies, and that we are accused of attempting to construct the universe by methods that would baffle Omnipotence itself, because they are simply absurd. In this aspect of them, indeed, such speculations are necessarily futile, because no mind can grasp all the complexities of even any one case, and it is useless to follow out an imaginary line of development which unexplained facts must contradict at every step. This is also, no doubt, the reason why all recent attempts at constructing "Phylogenies" are so changeable, and why no two experts can agree about almost any of them.

A second aspect in which such speculations are too partial, is in the unwarranted use which they make of analogy. It is not unusual to find such analogies as that between the embryonic development of the individual animal and the succession of animals in geological time placed on a level with that reasoning from analogy by which geologists apply modern causes to explain geological formations. No claim could be more unfounded. When the geologist studies ancient limestones built up of the remains of corals, and then applies the phenomena of modern coral reefs to explain their origin, he brings the latter to bear on the former by an analogy which includes not merely the apparent results, but the causes at work, and the conditions of their action, and it is on this that the validity of his comparison depends, in so far as it relates to similarity of mode of formation. But when we compare the development of an animal from an embryo cell with the progress of animals in time, though we have a curious analogy as to the steps of the process, the conditions and causes at work are known to be altogether dissimilar, and therefore we have no

evidence whatever as to identity of cause, and our reasoning becomes at once the most transparent of fallacies. Further, we have no right here to overlook the fact that the conditions of the embryo are determined by those of a previous adult, and that no sooner does this hereditary potentiality produce a new adult animal, than the terrible external agencies of the physical world, in presence of which all life exists, begin to tell on the organism, and after a struggle of longer or shorter duration it succumbs to death, and its substance returns into inorganic nature, a law from which even the longer life of the species does not seem to exempt it. All this is so plain and manifest that it is extraordinary that evolutionists will continue to use such partial and imperfect arguments. Another illustration may be taken from that application of the doctrine of natural selection to explain the introduction of species in geological time, which is so elaborately discussed by Sir C. Lyell in the last edition of his " Principles of Geology." The great geologist evidently leans strongly to the theory, and claims for it the " highest degree of probability," yet he perceives that there is a serious gap in it ; since no modern fact has ever proved the origin of a new species by modification. Such a gap, if it existed in those grand analogies by which he explained geological formations through modern causes, would be admitted to be fatal.

A third illustration of the partial character of these hypotheses may be taken from the use made of the theory deduced from modern physical discoveries, that life must be merely a product of the continuous operation of physical laws. The assumption—for it is nothing more—that the phenomena of life are produced merely by some arrangement of physical forces, even if it be admitted to be true, gives only a partial explanation of the possible origin of life. It does not account for the fact that life, as a force, or combination of forces, is set in antagonism to all other forces. It does not account for the

marvellous connection of life with organization. It does not account for the determination and arrangement of forces implied in life. A very simple illustration may make this plain. If the problem to be solved were the origin of the mariner's compass, one might assert that it is wholly a physical arrangement, both as to matter and force. Another might assert that it involves mind and intelligence in addition. In some sense both would be right. The properties of magnetic force and of iron or steel are purely physical, and it might even be within the bounds of possibility that somewhere in the universe a mass of natural loadstone may have been so balanced as to swing in harmony with the earth's magnetism. Yet we would surely be regarded as very credulous if we could be induced to believe that the mariner's compass has originated in that way. This argument applies with a thousandfold greater force to the origin of life, which involves even in its simplest forms so many more adjustments of force and so much more complex machinery.

Fourthly, these hypotheses are partial, inasmuch as they fail to account for the vastly varied and correlated interdependencies of natural things and forces, and for the unity of plan which pervades the whole. These can be explained only by taking into the account another element from without. Even when it professes to admit the existence of a God, the evolutionist reasoning of our day contents itself altogether with the physical or visible universe, and leaves entirely out of sight the power of the unseen and spiritual, as if this were something with which science has nothing to do, but which belongs only to imagination or sentiment. So much has this been the case, that when recently a few physicists and naturalists have referred to the "Unseen Universe," they have seemed to be teaching new and startling truths, though only reviving some of the oldest and most permanent ideas of our race. From the dawn of human thought it has been the conclusion alike of philoso-

phers, theologians, and the common sense of mankind, that the seen can be explained only by reference to the unseen, and that any merely physical theory of the world is necessarily partial. This, too, is the position of our sacred Scriptures, and is broadly stated in their opening verse, and indeed it lies alike at the basis of all true religion and all sound philosophy, for it must necessarily be that "the things that are seen are temporal, the things that are unseen, eternal." With reference to the primal aggregation of energy in the visible universe, with reference to the introduction of life, with reference to the soul of man, with reference to the heavenly gifts of genius and prophecy, with reference to the introduction of the Saviour Himself into the world, and with reference to the spiritual gifts and graces of God's people, all these spring, not from sporadic acts of intervention, but from the continuous action of God and the unseen world; and this, we must never forget, is the true ideal of creation in Scripture and in sound theology. Only in such exceptional and little influential philosophies as that of Democritus, and in the speculations of a few men carried off their balance by the brilliant physical discoveries of our age, has this necessarily partial and imperfect view been adopted. Never, indeed, was its imperfection more clear than in the light of modern science.

Geology, by tracing back all present things to their origin, was the first science to establish on a basis of observed facts the necessity of a beginning and end of the world. But even physical science now teaches us that the visible universe is a vast machine for the dissipation of energy; that the processes going on in it must have had a beginning in time, and that all things tend to a final and helpless equilibrium. This necessity implies an unseen power, an invisible universe, in which the visible universe must have originated, and to which its energy is ever returning. The hiatus between the seen and the unseen may be bridged over by the conceptions of atomic vortices of

force, and by the universal and continuous ether; but whether or not, it has become clear that the conception of the unseen, as existing, has become necessary to our belief in the possible existence of the physical universe itself, even without taking life into account.

It is in the domain of life, however, that this necessity becomes most apparent; and it is in the plant that we first clearly perceive a visible testimony to that unseen which is the counterpart of the seen. Life in the plant opposes the outward rush of force in our system, arrests a part of it on its way, fixes it as potential energy, and thus, forming a mere eddy, so to speak, in the process of dissipation of energy, it accumulates that on which animal life and man himself may subsist, and assert for a time supremacy over the seen and temporal on behalf of the unseen and eternal. I say, for a time, because life is, in the visible universe, as at present constituted, but a temporary exception, introduced from that unseen world where it is no longer the exception but the eternal rule. In a still higher sense, then, than that in which matter and force testify to a Creator, organization and life, whether in the plant, the animal, or man, bear the same testimony, and exist as outposts put forth in the succession of ages from that higher heaven that surrounds the visible universe. In them, too, Almighty power is no doubt conditioned or limited by law; yet they bear more distinctly upon them the impress of their Maker, and, while all explanations of the physical universe which refuse to recognise its spiritual and unseen origin must necessarily be partial and in the end incomprehensible, this destiny falls more quickly and surely on the attempt to account for life and its succession on merely materialistic principles.

Here again, however, we must bear in mind that creation, as maintained against such materialistic evolution, whether by theology, philosophy, or Holy Scripture, is necessarily a continuous, nay, an eternal, influence, not an intervention of dis-

connected acts. It is the true continuity, which includes and binds together all other continuity.

It is here that natural science meets with theology, not as an antagonist, but as a friend and ally in its time of greatest need; and I must here record my belief that neither men of science nor theologians have a right to separate what God in Holy Scripture has joined together, or to build up a wall between nature and religion, and write upon it, "no thoroughfare." The science that does this must be impotent to explain nature, and without hold on the higher sentiments of man. The theology that does this must sink into mere superstition.

In conclusion, can we formulate a few of the general laws, or perhaps I had better call them the general conclusions, respecting life, in which all Palæontologists may agree. Perhaps it is not possible to do this at present satisfactorily, but the attempt may do no harm. We may, then, I think, make the following affirmations :—

1. The existence of life and organization on the earth is not eternal, or even coeval with the beginning of the physical universe, but may possibly date from Laurentian or immediately pre-Laurentian ages.

2. The introduction of new species of animals and plants has been a continuous process, not necessarily in the sense of derivation of one species from another, but in the higher sense of the continued operation of the cause or causes which introduced life at first. This, as already stated, I take to be the true theological or Scriptural as well as scientific idea of what we ordinarily and somewhat loosely term creation.

3. Though thus continuous, the process has not been uniform; but periods of rapid production of species have alternated with others in which many disappeared and few were introduced. This may have been an effect of physical cycles reacting on the progress of life.

4. Species, like individuals, have greater energy and vitality in

their younger stages, and rapidly assume all their varietal forms, and extend themselves as widely as external circumstances will permit. Like individuals also, they have their periods of old age and decay, though the life of some species has been of enormous duration in comparison with that of others; the difference appearing to be connected with degrees of adaptation to different conditions of life.

5. Many allied species, constituting groups of animals and plants, have made their appearance at once in various parts of the earth, and these groups have obeyed the same laws with the individual and the species in culminating rapidly, and then slowly diminishing, though a large group once introduced has rarely disappeared altogether.

6. Groups of species, as genera and orders, do not usually begin with their highest or lowest forms, but with intermediate and generalized types, and they show a capacity for both elevation and degradation in their subsequent history.

7. The history of life presents a progress from the lower to the higher, and from the simpler to the more complex, and from the more generalized to the more specialized. In this progress new types are introduced, and take the place of the older ones, which sink to a relatively subordinate place, and become thus degraded. But the physical and organic changes have been so correlated and adjusted that life has not only always maintained its existence, but has been enabled to assume more complex forms, and thus older forms have been made to prepare the way for newer, so that there has been, on the whole, a steady elevation culminating in man himself. Elevation and specialization have, however, been secured at the expense of vital energy and range of adaptation, until the new element of a rational and inventive nature was introduced only in the case of man.

8. In regard to the larger and more distinct types, we cannot find evidence that they have, in their introduction,

been preceded by similar forms connecting them with previous groups; but there is reason to believe that many supposed representative species in successive formations are really only races or varieties.

9. In so far as we can trace their history, specific types are permanent in their characters from their introduction to their extinction, and their earlier varietal forms are similar to their later ones.

10. Palæontology furnishes no direct evidence, perhaps never can furnish any, as to the actual transformation of one species into another, or as to the actual circumstances of creation of a species; but the drift of its testimony is to show that species come in *per saltum*, rather than by any slow and gradual process.

11. The origin and history of life cannot, any more than the origin and determination of matter and force, be explained on purely material grounds, but involve the consideration of power referable to the unseen and spiritual world.

Different minds may state these principles in different ways, but I believe that in so far as palæontology is concerned, in substance they must hold good, at least as steps to higher truths. And now allow me to say that we should be thankful that it is given to us to deal with so great questions, and that in doing so, deep humiliation, earnest seeking for truth, patient collection of all facts, self-denying abstinence from hasty generalizations, forbearance and generous estimation with regard to our fellow labourers, and reliance on that Divine Spirit which has breathed into us our intelligent life, and is the source of all true wisdom, are the qualities which best become us.

But while the principles noted above may be said to be known laws of the apparition of new forms of life, they do not reach to the secondary efficient causes of the introduction of new species. What these may ultimately prove to be, to

what extent they can be known by us, and to what extent they may include processes of derivation, it is impossible now to say. At present we must recognise in the prevailing theories on the subject merely the natural tendency of the human mind to grasp the whole mass of the unknown under some grand general hypothesis, which, though perhaps little else than a figure of speech, satisfies for the moment. We are dealing with the origin of species precisely as the alchemists did with chemistry, and as the Plutonists and Neptunists did with geology; but the hypotheses of to-day may be the parents of investigations which will become real science to-morrow. In the meantime it is safe to affirm that whatever amount of truth there may be in the several hypotheses which have engaged our attention, there is a creative force above and beyond them, and to the threshold of which we shall inevitably be brought, after all their capabilities have been exhausted by rigid investigation of facts. It is also consolatory to know that species, in so far as the Modern period, or any one past geological period may be concerned, are so fixed that for all practical purposes they may be regarded as unchanging. They are to us what the planets in their orbits are to the astronomer, and speculations as to the origin of species are merely our nebular hypotheses as to the possible origin of worlds and systems.

REFERENCES:—Address as Vice-President of American Association at Detroit, 1875. "The Chain of Life in Geological Time," London, 1879. Addresses to Natural History Society of Montreal, published in *Canadian Naturalist*, "Apparition of Animal Forms," *Princeton Review.*



THE GENESIS AND MIGRATIONS OF PLANTS.

DEDICATED TO THE MEMORY OF

DR. OSWALD HEER,

THE ABLE AND SUCCESSFUL STUDENT OF THE LATER FLORAS OF THE NORTHERN HEMISPHERE.

Geological Periods as Related to Plants—Arctic Origin of Floras—The Devonian Flora—Arctic Climates of the Past—History of Some Modern Forms—Laws of the Succession





VEGETATION OF THE MIDDLE DEVONIAN OR ERIAN, restored from actual specimens (p. 202).

CHAPTER VIII.

THE GENESIS AND MIGRATIONS OF PLANTS.

IF, for convenience of reference, we divide the whole history of the earth, from the time when a solid crust first formed on its surface and began to be ridged up into islands or mountains in the primeval ocean, into four great periods, we shall find that each can be characterized by some features in relation to the world of plants.

That Archean age, in which the oldest known beds of rocks were produced—rocks now greatly crumpled by the first movements of the thin crust, and hardened and altered by heat and pressure—has, it is true, little to tell us. But, as elsewhere stated, even it has beds of Carbon in the form of Graphite—veritable altered coal seams—which the analogy of later formations would lead us to believe must have been accumulated by the growth of plants. This growth is indeed the only known cause capable of producing such effects. If we should ever be fortunate enough to find beds of the Laurentian series in an unaltered state, we may hope to know something of this old flora. Nor need we be surprised if it should prove of higher grade and more noble development than we should at first sight anticipate. If there ever was a time when vegetation alone possessed the earth, and when there were no animals to devour or destroy it, we might expect to find it in its first and best estate, perhaps not comparable in variety and complexity of parts with the flora of the modern world, but grand in its luxuriance and majesty. Of such discoveries, however, we have no certain indication at present.

If such a primeval flora as that above indicated ever existed, it must have perished utterly before the incoming of the next great age of the world—that known as the Palæozoic, whose rocks are surpassingly rich in the remains of animals, especially those of the lower or invertebrate classes and those that inhabit the waters.

In the oldest Palæozoic rocks we find no plants certainly terrestrial, but abundance of Algæ or seaweeds, and some gigantic members of the vegetable kingdom which seem to have been trees, with structures more akin to those of aquatic than to those of land plants.[1] At a somewhat early stage, however, in the rocks of this period, we discover a few undoubted land plants.[2] These seem to be allied to the modern Club-mosses and to their humble relations, the pillworts[3] and other small plants of similar structure found in ponds and swamps. Some of them, indeed, appear to be intermediate between these groups. All these plants are Cryptogams, or destitute of true flowers, but do not belong to the lowest forms of that type. Thus, so far as we know, plant life on the land began possibly with certain large trees of algoid structures, and more certainly with the club mosses and pillworts and their allies, and these last in the form of species not tree-like in dimensions, but of very moderate size. The structures of these plants are already sufficiently well known to inform us that the plan and functions of the root, stem and leaf, and of spores and spore case were set up; and that the structures and functions of vegetable cells, fibres and some kinds of vessels were perfected, and all the apparatus introduced necessary for the fertilization and reproduction of plants of some degree of complexity. At the same time, the peculiar structures of the higher Algæ were brought to a pitch of perfection not surpassed

[1] Nematophyton, etc. See "Geological History of Plants."

[2] Psilophyton, Protannularia, etc.

[3] Rhizocarpeæ.

if equalled in modern times, and which may have enabled plants so constructed to exist even on the land.

From these beginnings in the early Palæozoic, the progress of the vegetable kingdom went on, until, in the later parts of that great period, the Devonian and Carboniferous eras, it culminated in those magnificent forests which have left so many interesting remains, and which accumulated the materials of our great beds of coal. In these the families of the Club mosses, the Ferns and the Mare's-tails attained to a perfection in structure and size altogether unexampled in the modern world, and may be said to have overspread the earth almost to the exclusion of other trees. Here, however, two new families come in of higher grade, and leading the way to the flowering plants. These are the Pines and their allies and the Cycads, and certain intermediate forms, neither Pines nor Cycads, but allied to both.[1] This wonderful flora, which we have now the materials to reproduce in imagination almost in its entirety, decays and passes away in the Permian system, the last portion of the Palæozoic, and in entering into the third great period of the earth's history—the Mesozoic, we again find an almost entire change of vegetation. Here, however, we are able to understand something of the reasons of this. The Palæozoic floras seem to have originated in the North, and propagated themselves southward till they replenished the earth, and they were favoured by the existence at that time of vast swampy flats extending over great areas of the yet imperfectly elaborated continents. The Mesozoic floras, on the other hand, seem to have been of Southern or equatorial origin, and to have followed up the older vegetation as it decayed and disappeared,

[1] *Cordaites*, etc. As I have elsewhere shown, these are distinct sub-floras in the Lower, Middle and Upper Devonian, and in the Lower, Middle and Upper Carboniferous and Permian, sufficiently different to allow these periods to be determined by the evidence of these fossil plants. Reports prepared for Geological Survey of Canada.

or retreated in its old age to its northern home. There is, of course, much in all this that we do not understand, but the general fact seems certain.

The early Mesozoic is altogether peculiar. It shows a vast predominance of Cycads, Pines and Ferns, to the exclusion both of the gigantic Cryptogams of the Palæozoic and of the ordinary exogenous trees of the modern time. It has a strange, weird aspect, and more resembles that of some warm islands of the southern hemisphere at present, than anything else known to us. It is as if the flora of some southern island had migrated and invaded all parts of the world. The geographical and climated conditions which permitted this must have been of a character different from those both of earlier and later times.

As we approach to the termination of the Mesozoic, which, in regard to animal life, is the age of reptiles, a new and strange development meets us. We find beds filled with leaves of broad-leaved plants similar to those of our modern woods, and in most cases apparently belonging to the same genera with plants now living, and this new type of vegetation persists to the present, though with marked differences of species in successive eras, as in the Middle and Upper Cretaceous, and the Lower, Middle and Upper Kainozoic, or Tertiary. It is noteworthy that while this new vegetation not only altogether supersedes the great Cryptogamous forests of the Palæozoic, but replaces the Cycads of the immediately preceding eras, the Pines retain all their prominence and grandeur, and even seem to excel in number of species, in breadth of dispersion, and in magnitude of growth their successors in the present world.

While in the latter Cretaceous and Early Tertiary, the northern hemisphere at least seems to have enjoyed an exceptionally warm climate, the later Tertiary introduces that period of cold known as the Glacial age. While there is no doubt that the intensity of this glaciation has been greatly

exaggerated by extreme glacialists, and while it is certain that some vegetation, and this not altogether of Arctic types, continued to exist throughout this period, even in the now temperate regions of our continents, it is evident that a great reduction of the exuberance of the flora occurred by the removal of many species, and that the present flora of the northern hemisphere is inferior in variety and magnificence to that of the Middle Tertiary, just as it is found that the Mammalian fauna of our continents has since that time been reduced both in the number and magnitude of its species.

If the reader has followed this general sketch, he will be prepared to appreciate some examples of a more detailed character relating to the floras of different periods, and some discussions of general points relating to the genesis and vicissitudes of the vegetable kingdom.

The origination of the more important floras which have occupied the northern hemisphere in geological times, not, as one might at first sight suppose, in the sunny climates of the South, but under the arctic skies, is a fact long known or suspected. It is proved by the occurrence of fossil plants in Greenland, in Spitzbergen, and in Grinnell Land, under circumstances which show that these were their primal homes. The fact bristles with physical difficulties, yet is fertile of the most interesting theoretical deductions, to reach which we may well be content to wade through some intricate questions. Though not at all a new fact, its full significance seems only recently to have dawned on the minds of geologists, and within recent years it has produced a number of memoirs and addresses to learned societies, besides many less formal notices.[1]

[1] Saporata, "Ancienne Vegetation Polaire"; Hooker, Presidential Address to Royal Society, 1878; Thistleton Dyer, "Lecture on Plant Distribution"; Mr. Starkie Gardner, Letters in *Nature*, 1878, etc. The basis of most of these brochures is to be found in Heer's "Flora Fossilis Arctica."

The earliest suggestion on this subject known to the writer is that of my old and dear friend, Professor Asa Gray, in 1867, with reference to the probable northern source of the related floras of North America and Eastern Asia. With the aid of new facts disclosed by Heer and Lesquereux, Gray returned to the subject in 1872, and more fully developed this conclusion with reference to the Tertiary floras,[1] and still later he further discussed these questions in an able lecture on "Forest Geography and Archæology."[2] In this he puts the case so well and tersely that I may quote the following sentences as a text for what follows:—

"I can only say, at large, that the same species (of Tertiary fossil plants) have been found all round the world; that the richest and most extensive finds are in Greenland; that they comprise most of the sorts which I have spoken of, as American trees which once lived in Europe—Magnolias, Sassafras, Hickories, Gum-trees, our identical Southern Cypress (for all we can see of difference), and especially *Sequoias*, not only the two which obviously answer to the two Big-trees now peculiar to California, but several others; that they equally comprise trees now peculiar to Japan and China—three kinds of Gingko-trees, for instance, one of them not evidently distinguishable from the Japan species which alone survives; that we have evidence, not merely of Pines and Maples, Poplars, Birches, Lindens, and whatever else characterize the temperate-zone forests of our era, but also of particular species of these, so like those of our own time and country, that we may fairly reckon them as the ancestors of several of ours. Long genealogies always deal more or less in conjecture; but we appear to be within the limits of scientific inference when we announce that our existing temperate trees came from the north, and within the bounds of high probability when we

[1] Address to American Association.

[2] *American Journal of Science*, xvi., 1878.

claim not a few of them as the originals of present species. Remains of the same plants have been found fossil in our temperate region, as well as in Europe."

Between 1860 and 1870 the writer was engaged in working out all that could be learned of the Devonian plants of Eastern America, the oldest known flora of any richness, and which consists almost exclusively of gigantic, and to us grotesque, representatives of the Club mosses, Ferns, and Mares'-tails, with some trees allied to the Cycads and Pines. In this pursuit nearly all the more important localities were visited, and access was had to the large collections of Professor Hall and Professor Newberry in New York and Ohio, as well as to those of the Geological Survey of Canada, and to those made in the remarkable plant-bearing beds of St. John, New Brunswick, by Messrs. Matthew and Hartt. In the progress of these researches, which developed an unexpectedly rich assemblage of species, the northern origin of this old flora seemed to be established by its earlier culmination in the north-east, in connection with the growth of the American land to the southward, which took place after the great Upper Silurian subsidence, by elevations which began in the north, while those portions of the continent to the south-west still remained under the sea.

When, in 1870, the labours of those ten years were brought before the Royal Society of London, in the Bakerian Lecture of that year, and in a memoir illustrating no less than one hundred and twenty-five species of plants older than the great Carboniferous system, these deductions were stated in connection with the conclusions of Hall, Logan, and Dana, as to the distributions of sediment along the north-east side of the American continent, and the anticipation was hazarded that the oldest Palæozoic floras would be discovered to the north of Newfoundland. Mention was also made of the apparent earlier and more copious birth of the Devonian flora in

America than in Europe, a fact which is itself connected with the greater northward extension of this continent.

Unfortunately the memoir containing these results was not published by the Royal Society, and its publication was secured in a less perfect form only in the reports of the Geological Survey of Canada. The part of the memoir relating to Canadian fossil plants, with a portion of the theoretical deductions, was published in a report issued in 1871.[1] In this report the following language was used:—

"In Eastern America, from the Carboniferous period onward, the centre of plant distribution has been the Appalachian chain. From this the plants and sediments extended westward in times of elevation, and to this they receded in times of depression. But this centre was non-existent before the Devonian period, and the centre of this must have been to the north-east, whence the great mass of older Appalachian sediment was derived. In the Carboniferous period there was also an eastward distribution from the Appalachians, and links of connection in the Atlantic bed between the floras of Europe and America. In the Devonian such connection can have been only far to the north-east. It is therefore in Newfoundland, Labrador, and Greenland that we are to look for the oldest American flora, and in like manner on the border of the old Scandinavian nucleus for that of Europe."

"Again, it must have been the wide extension of the sea of the Corniferous limestone that gave the last blow to the remaining flora of the Lower Devonian: and the re-elevation in the middle of that epoch brought in the Appalachian ridges as a new centre, and established a connection with Europe which introduced the Upper Devonian and Carboniferous floras. Lastly, from the comparative richness of the later Erian [2] flora

[1] "Fossil Plants of the Devonian and Upper Silurian Formations of Canada," pp. 92, twenty plates. Montreal, 1871.

[2] The term Erian is used as synonymous with Devonian, and prob-

in Eastern America, especially in the St. John beds, it might be a fair inference that the north-eastern end of the Appalachian ridge was the original birthplace or centre of creation of what we may call the later Palæozoic flora, or a large part of that flora."

When my paper was written I had not seen the account published by the able Swiss palæobotanist Heer, of the remarkable Devonian flora of Bear Island, near Spitzbergen.[1] From want of acquaintance with the older floras of America and Western Europe, Heer fell into the unfortunate error of regarding the Bear Island plants as Lower Carboniferous, a mistake which his great authority has tended to perpetuate, and which has even led to the still graver error of some European geologists, who do not hesitate to regard as Carboniferous the fossil plants of the American deposits from the Hamilton to the Chemung groups inclusive, though these belong to formations underlying the oldest Carboniferous, and characterized by animal remains of unquestioned Devonian age. In 1872 I addressed a note to the Geological Society of London on the subject of the so-called "Ursa stage" of Heer, showing that though it contained some forms not known at so early a date in temperate Europe, it was clearly Devonian when tested by North American standards; but that in this high latitude, in which, for reasons stated in the report above referred to, I believed the Devonian plants to have originated, there might be an intermixture of the two floras. But such a mixed group should in that latitude be referred to a lower horizon than if found in temperate regions.

Between 1870 and 1873 my attention was turned to the two subfloras intermediate between those of the Devonian and the

ably should be preferred to it, as pointing to the best development of this formation known, which is on the shores of Lake Erie.

[1] Trans. Swedish Academy, 1871, *Journal London Geological Society*, vol. xxviii.

coal formation, the floras of the Lower Carboniferous (Sub-carboniferous of some American geologists) and the Millstone Grit, and in a report upon these [1] similar deductions were expressed. It was stated that in Newfoundland and Northern Cape Breton the coal formation species come in at an early part of that period, and as we proceed southward they belong to progressively newer portions of the Carboniferous system. The same fact is observed in the coal beds of Scotland, as compared with those of England, and it indicates that the coal formation flora, like that of the Devonian, spread itself from the north, and this accords with the somewhat extensive occurrence of Lower Carboniferous rocks and fossils in the Parry Islands and elsewhere in the Arctic regions.[2]

Passing over the comparatively poor flora of the earlier Mesozoic, consisting largely of cycads, pines, and ferns, which, as we have seen, is probably of southern origin, and is as yet little known in the arctic, though represented, according to Heer, by the supposed Jurassic flora of Cape Boheman, we find, especially at Komé and Atané in Greenland, an interesting occurrence of those earliest precursors of the truly modern forms of plants which appear in the Cretaceous, the period of the English chalk, and of the New Jersey greensands. There are two plant groups of this age in Greenland, one, that of Komé consists almost entirely of ferns, cycads, and pines, and is of decidedly Mesozoic aspect. This was regarded by Heer as Lower Cretaceous. The other, that of Atané, holds remains of many modern temperate genera, as *Populus*, *Myrica*, *Ficus*, *Sassafras*, and *Magnolia*. This he regards as Middle Cretaceous. Above this is the Patoot series, with many exogenous trees of modern genera, and representing the Upper Cretaceous. Resting upon these Upper Cretaceous beds, without

[1] "Fossil Plants of Lower Carboniferous and Millstone Grit Formations of Canada," pp. 47, 10 plates. Montreal, 1873.

[2] G. M. Dawson, "Report on Arctic Regions of Canada."

the intervention of any other formation,[1] are beds rich in plants of much more modern appearance, and referred by Heer to the Miocene period, a reference which appeared at the time to be warranted by comparison with the Tertiary plants of Europe, but, as we shall see, not with those of America. Still farther north this so-called Miocene assemblage of plants appears in Spitzbergen and Grinnell Land; but there, owing to the predominance of trees allied to the spruces, it has a decidedly more boreal character than in Greenland, as might be anticipated from its nearer approach to the pole.[2]

If now we turn to the Cretaceous and Tertiary floras of Western America, as described by Lesquereux, Newberry, and Ward, we find in the lowest Cretaceous rocks known there until very recently—those of the Dakota group, which may be in the lower part of the Middle Cretaceous—a series of plants[3] essentially similar to those of the Middle Cretaceous of Greenland. To these I have been able to add, through the researches of Mr. Richardson and Dr. G. M. Dawson, a still earlier flora, that of the Kootanie and Queen Charlotte Island formations, as old as the Gault and Wealden. It wants the broad-leaved plants of the Dakota, and consists mainly of pines, cycads, and ferns; and only in its upper part contains a few forerunners of the exogens.[4] These plants occur in beds indicating shallow sea conditions as prevalent in the interior of America, causing, no doubt, a warm climate in the north. Overlying this plant-bearing formation we have an oceanic limestone (the Niobrara), corresponding in many respects to

[1] Nordenskiöld, Expedition to Greenland, *Geological Magazine*, 1872.

[2] Yet even here the Bald Cypress (*Taxodium distichum*), or a tree nearly allied to it, is found, though this species is now limited to the Southern States. Fielden and De Rance, *Journal of Geological Society*, 1878.

[3] Lesquereux, Report on Cretaceous Flora. The reader not interested in American details may pass over to the middle of page 213.

[4] This flora has since been described in Virginia and Maryland by Fontaine, and has been recognised in Montana by Newberry.

the European chalk, and containing similar microscopic organisms. This extends far north into the British territory,[1] indicating farther subsidence and the prevalence of a vast Mediterranean Sea, filled with warm water from the equatorial currents, and not invaded by cold waters from the north. This is succeeded by Upper Cretaceous deposits of clay and sandstone, with marine remains, though very sparsely distributed; and these show that further subsidence or denudation in the north had opened a way for the arctic currents, producing a fall of temperature at the close of the Cretaceous, and partially filling up the Mediterranean of that period.

Of the flora of the Middle and Upper Cretaceous periods, which must have been very long, we know something in the interior regions through the plants of Dunvegan and Peace River;[2] and on the coast of British Columbia we have the remarkable Cretaceous coalfield of Vancouver's Island, which holds the remains of plants of modern genera, including species of fan palm, ginkgo, evergreen oak, tulip tree, and other forms proper to a warm temperature or subtropical climate. They probably indicate a warmer climate as then prevalent on the Pacific coast than in the interior, and in this respect correspond with a meagre transition flora, intermediate between the Cretaceous and Eocene or earliest Tertiary of the interior regions, and named by Lesquereux the Lower Lignitic.

Immediately above these Upper Cretaceous beds we have the great Lignite Tertiary of the west—the Laramie group of recent American reports[3]—abounding in fossil plants, proper to a temperate climate, at one time regarded as Miocene, but now known to be Lower Eocene.[4] These beds, with their

[1] G. M. Dawson, Report on Forty-ninth Parallel.

[2] Trans. Royal Society of Canada.

[3] Ward, Repts. and Bulletins Am. Geol. Survey.

[4] Lesquereux's Tertiary Flora; White and Ward on the Laramie Group; Stevenson, Geological Relations of Lignitic Groups, Am. Phil. Soc., June, 1875.

characteristic plants, have been traced into the British territory north of the forty-ninth parallel, and it has been shown that their fossils are identical with those of the McKenzie River Valley, described by Heer as Miocene, and probably also with those of Alaska, referred to the same age.[1] Now this truly Eocene flora of the temperate and northern parts of America has so many species in common with that called Miocene in Greenland, that its identity can scarcely be doubted. These facts have led me to doubt the Miocene age of the upper plant-bearing beds of Greenland, and more recently Mr. J. Starkie Gardner has shown from comparison with the Eocene flora of England and other considerations, that they are really of that earlier date.[2]

In looking at these details, we might perhaps suppose that no conditions of climate could permit the vegetation of the neighbourhood of Disco in Greenland to be identical with that of Colorado and Missouri, at a time when little difference of level existed in the two regions. Either the southern flora migrated north in consequence of a greater amelioration of climate, or the northern flora moved southward as the climate became colder. The same argument, as Gardner has ably shown, applies to the similarity of the Tertiary plants of temperate Europe to those of Greenland. If Greenland required a temperature of about 50°, as Heer calculates, to maintain its "Miocene" flora, the temperature of England must have been at least 70°, and that of the south-western States still warmer. It is to be observed, however, that the geographical arrange-

[1] G. M. Dawson, Report on the Geology of the Forty-ninth Parallel, 1875, where full details on these points may be found.

[2] *Nature*, Dec. 12th, 1878; Publications Palæontographical Society; Reports to British Association. It seems certain that the so-called Miocene of Bovey Tracey in Devon, and of Mull in Scotland, is really Eocene. The Tertiary plant-bearing beds of Greenland are said by Nathorst to rest unconformably on the Cretaceous, and are characterized by *M'Clintockia* and other forms known in the Eocene of Great Britain and Ireland.

ments of the American land in Cretaceous and early Eocene times, included the existence of a great inland sea of warm water extending at some periods as far north as the latitude of 55°, and that this must have tended to much equality of climatical conditions.

We cannot certainly affirm anything respecting the origin and migrations of these floras, but there are some probabilities which deserve attention. The ferns and cycads of the so-called Lower Cretaceous of Greenland are nothing but a continuation of the previous Jurassic flora. Now this was established at an equally early date in the Queen Charlotte Islands,[1] and still earlier in Virginia.[2] The presumption is, therefore, that it came from the south. It has indeed the facies of a southern hemisphere and insular flora, and probably spread itself northward as far as Greenland at a time when the American land was long, narrow, and warm, and when the ocean currents were carrying tepid water far toward the arctic regions. The flora which succeeds this in the sections at Atané and Patoot has no special affinities with the southern hemisphere, and is of a warm temperate and continental character. It is very similar in its general aspect to that of the Dakota group farther to the south, and this is probably Middle Cretaceous. This flora must have originated either somewhere in temperate America, or within the arctic circle, and it must have replaced the older one by virtue of increasing subsidence and gradual change of climate. It must therefore have been connected with the depression of the land which took place in the course of the Cretaceous. During this movement it spread over all Western America, and as the land again arose from the sea of the Niobrara chalk, it assumed an aspect more suited to a cool climate, or moved southward,

[1] Reports Geological Survey of Canada.

[2] Fontaine has well described the Mesozoic flora of Virginia, *American Journal of Science*, January, 1879.

and finally abandoned the Arctic regions, perhaps continuing to exist on the Pacific coast, and in sheltered places in the north, till the warm inland seas of the Upper Cretaceous had given place to the wide plains and landlocked brackish seas or fresh-water lakes of the Laramie period (Eocene). Thus the true Upper Cretaceous marks in the interior a cooler period intervening between the Middle Cretaceous and the Lower Eocene floras of Greenland.

This latter established itself in Greenland, and probably all around the Arctic circle, in the mild period of the earliest Eocene, and as the climate of the northern hemisphere became gradually reduced from that time till the end of the Pliocene, it marched on over both continents to the southward, chased behind by the modern arctic flora, and eventually by the frost and snow of the Glacial age. This history may admit of correction in details; but, so far as present knowledge extends, it is in the main not far from the truth.

Perhaps the first great question which it raises is that as to the causes of the alternations of warm and cold climates in the north, apparently demanded by the vicissitudes of the vegetable kingdom. Here we may set aside the idea that in former times plants were suited to endure greater cold than at present. It is true that some of the fossil Greenland plants are of unknown genera, and many are new species to us; but we are on the whole safe in affirming that they must have required conditions similar to those necessary to their modern representatives, except within such limits as we now find to hold in similar cases among existing plants. Still we know that at the present time many species found in the equable climate of England will not live in Canada, though species to all appearance similar in structure are natives of the latter. There is also some reason to suppose that species, when new, may have greater hardiness and adaptability than when in old age, and verging toward extinction. In any case, these facts can account

for but a small part of the phenomena, which require to be explained by physical changes affecting the earth as a whole, or at least the northern hemisphere. Many theoretical views have been suggested on this subject, which will be found discussed elsewhere, and perhaps the most practical way to deal with them here will be to refer to the actual conditions known to have prevailed in connection with the introduction and distribution of the principal floras which have succeeded each other in geological history.

If we can assume that all the carbon now sealed up in limestones and in coal was originally floating in the atmosphere as carbon dioxide, then we would have a cause which might seriously have affected the earlier land floras—that, for instance, which may have existed in the Eozoic age, and those well known to us in the Palæozoic. Such an excess of carbonic acid would have required some difference of constitution in the plants themselves; it would have afforded them a superabundance of wood-forming nutriment, and it would have acted as an obstacle to the radiation of heat from the earth, almost equal to the glass roof of a greenhouse, thus constituting a great corrective of changes of temperature. Under such circumstances we might expect a peculiar and exuberant vegetation in the earlier geological ages, though this would not apply to the later in any appreciable degree. In addition to this we know that the geographical arrangements of our continents were suited to the production of a great uniformity of climate. Taking the American continent as the simpler, we know that in this period there existed in the interior plateau between the rudimentary eastern and western mountains a great inland sea, so sheltered from the north that its waters contained hundreds of species of corals, growing with a luxuriance unsurpassed in the modern tropics. On the shores and islands of such a sea we do not wonder that there should have been tree ferns and gigantic lycopods. In the succeeding Carboniferous,

vast areas, both on the margins and in the interior of the continent, were occupied with swampy flats and lagoons, the atmosphere of which must have been loaded with vapour, and rich in compounds of carbon, though the temperature may have been lower than in the Devonian. There still remained, however, more especially in the west, a remnant of the old inland sea, which must have greatly aided in carrying a warm temperature to the north.

If now we pass to the succeeding Jurassic age, we find a more meagre and less widely distributed flora, corresponding to less favourable geographical and climatal conditions, while in the Cretaceous and Eocene ages a return to the old condition of a warm Mediterranean in continuation of the Gulf of Mexico gave those facilities for vegetable growth, which carried plants of the temperate zone as far north as Greenland.

It thus appears that those changes of physical geography and of the ocean currents to which reference is so often made in these papers, apply to the question of the distribution of plants in geological time.

These same causes may help us to deal with the peculiarities of the great Glacial age, which may have been rendered exceptionally severe by the combination of several of the continental and oceanic causes of refrigeration. We must not imagine, however, that the views of those extreme glacialists, who suppose continental ice caps reaching half way to the equator, are borne out by facts. In truth, the ice accumulating round the pole must have been surrounded by water, and there must have been tree-clad islands in the midst of the icy seas, even in the time of greatest refrigeration. This is proved by the fact that in the lower Leda clay of Eastern Canada, which belongs to the time of greatest submergence, and whose fossil shells show sea water almost at the freezing point, there are leaves of poplars and other plants which must have been drifted from neighbouring shores. Similar remains occur in

clays of similar origin in the basin of the great lakes and in the West, and are not Arctic plants, but members of the North Temperate flora.[1] These have been called "interglacial," but there is no evidence to prove that they are not truly glacial. Thus, while the arctic flora must have continued to exist within the Arctic circle in the Glacial age, we have evidence that those of the cold temperate and subarctic zones continued to exist pretty far north. At the same time the warm temperate flora would be driven to the south, except where sustained in insular spots warmed by the equatorial currents. It would return northward on the re-elevation of the land and the return of warmth.

If, however, our modern flora is thus one that has returned from the south, this would account for its poverty in species as compared with those of the early Tertiary. Groups of plants descending from the north have been rich and varied. Returning from the south they are like the shattered remains of a beaten army. This, at least, has been the case with such retreating floras as those of the Lower Carboniferous, the Permian, and the Jurassic, and possibly that of the Lower Eocene of Europe.

The question of the supply of light to an Arctic flora is much less difficult than some have imagined. The long summer day is in this respect a good substitute for a longer season of growth, while a copious covering of winter snow not only protects evergreen plants from those sudden alternations of temperature which are more destructive than intense frost, and prevents the frost from penetrating to their roots, but by the ammonia which it absorbs preserves their greenness. According to Dr. Brown, the Danish ladies of Disco long ago solved this problem.[2] He informs us that they cultivate in

[1] Pleistocene Plants of Canada, Dawson and Penhallow, *Bull. Geol. Socy.*, America, 1890. In Europe the Arctic flora extended, relatively to present climate, farther south.

[2] *Florula Discoana*, Botanical Society of Edinburgh, 1868.

their houses most of our garden flowers, as roses, fuchsias, and geraniums, showing that it is merely warmth, and not light that is required to enable a subtropical flora to thrive in Greenland. Even in Canada, which has a flora richer in some respects than that of temperate Europe, growth is effectually arrested by cold for nearly six months, and though there is ample sunlight there is no vegetation. It is indeed not impossible that in the plans of the Creator the continuous summer sun of the Arctic regions may have been made the means for the introduction, or at least for the rapid growth and multiplication, of new and more varied types of plants. It is a matter of familiar observation in Canada that our hardy garden flowers attain to a greater luxuriance and intensity of colour in those more northern latitudes where they have the advantage of long and sunny summer days.

Much, of course, remains to be known of the history of the old floras whose fortunes I have endeavoured to sketch, and which seem to have been driven like shuttlecocks from north to south, and from south to north, especially on the American continent, whose meridional extension seems to have given a field specially suited for such operations.

This great stretch of the western continent from north to south is also connected with the interesting fact that, when new floras are entering from the Arctic regions, they appear earlier in America than in Europe; and that in times when the old floras are retreating from the south, old genera and species linger longer in America. Thus, in the Devonian and Cretaceous new forms of those periods appear in America long before they are recognised in Europe, and in the modern epoch forms that would be regarded in Europe as Miocene still exist. Much confusion in reasoning as to the geological ages of the fossil flora has arisen from want of attention to this circumstance.

What we have learned respecting this wonderful history has

served strangely to change some of our preconceived ideas. We must now be prepared to admit that an Eden might exist even in Spitzbergen, that there are possibilities in this old earth of ours which its present condition does not reveal to us; that the present state of the world is by no means the best possible in relation to climate and vegetation; that there have been and might be again conditions which could convert the ice-clad Arctic regions into blooming paradises, and which, at the same time, would moderate the fervent heat of the tropics. We are accustomed to say that nothing is impossible with God; but how little have we known of the gigantic possibilities which lie hidden under some of the most common of His natural laws.

Yet these facts have been made the occasion of speculations as to the spontaneous development of plants without any direct creative intervention. It would, from this point of view, be a nice question to calculate how many revolutions of climate would suffice to evolve the first land plant; what are the chances that such plant would be so dealt with by physical changes as to be preserved and nursed into a meagre flora like that of the Upper Silurian or the Jurassic; how many transportations to Greenland would suffice to promote such meagre flora into the rich and abundant forests of the Upper Cretaceous, and to people the earth with the exuberant vegetation of the early Tertiary. Such problems we may never be able to solve. Probably they admit of no solution, unless we invoke the action of a creative mind, operating through long ages, and correlating with boundless power and wisdom all the energies inherent in inorganic and organic nature. Even then we shall perhaps be able to comprehend only the means by which, after specific types have been created, they may, by the culture of their Maker, be "sported" into new varieties or sub-species, and thus fitted to exist under different conditions, or to occupy higher places in the economy of nature.

Before venturing on such extreme speculations as some now current on questions of this kind, we would require to know the successive extinct floras as perfectly as those of the modern world, and to be able to ascertain to what extent each species can change, either spontaneously or under the influence of struggle for existence, or expansion under favourable conditions, and under Arctic semi-annual days and nights, or the shorter days of the tropics. Such knowledge, if ever acquired, it may take ages of investigation to accumulate. In any case the subject of this paper indicates one hopeful line of study with the object of arriving at some comprehension of the laws of creation.

While the facts above slightly sketched impress us with the grand progress of the vegetable kingdom in geological time, they equally show the persistence of vegetable forms as compared with that of the dead continental masses and the decay of some forms of life in favour of the introduction of others.

When we find in the glacial beds the leaves of trees still living in North America and Europe, and consider the vicissitudes of elevation and submergence of the land, and of Arctic and temperate climates which have occurred, we are struck with the persistence of the weak things of life, as compared with the changeableness of rocks and mountains. A superficial observer might think the fern or the moss of a granite hill a frail and temporary thing as compared with solid and apparently everlasting rock. But just the reverse is the case. The plant is usually older than the mountain. But the glacial age is a very recent thing. We have facts older than this. As hinted in a previous paper, in the Laramie clays associated with the Lignite beds of North-western Canada—beds of Lower Eocene or early Tertiary age—which were deposited before the Rocky Mountains or the Himalayas had reared their great peaks and ridges, and at a time when the whole geography of the northern hemisphere was different

from what it is at present—are remains of very frail and delicate plants which still live. I have shown that in these clays there exist, side by side, the Sensitive Fern, *Onoclea sensibilis*, and one of the delicate rock ferns, *Davallia tenuifolia*.[1] The first is still very abundant all over North America. The second has ceased to exist in North America, but still survives in the valleys of the Himalayas. These two little plants, once probably very widely diffused over the northern hemisphere, have continued to exist through the millenniums separating the Cretaceous from the present time, and in which the greater part of our continent was again and again under the sea, in which great mountain chains have been rolled up and sculptured into their present forms, and in which giant forms, both of animal and plant life, have begun, culminated and passed away. Truly God hath chosen the weak things of the world to confound those that are strong.

Other plants equally illustrate the decadence of important types of vegetable life. In the beautiful family of the Magnolias there exists in America a most remarkable and elegant tree, whose trunk attains sometimes a diameter of 7 feet and a height of 80 or 90 feet. Its broad deep green leaves are singularly truncate at the end, as if artificially cut off, and in spring it puts forth a wealth of large and brilliant orange and yellow flowers, from which it obtains the name of Tulip tree. It is the *Liriodendron tulipifera* of botanists, and the sole species of its genus. This Tulip tree has a history. All through the Tertiary beds we find leaves referable to the genus, and belonging not to one species only, but to several, and as we go back into the Cretaceous, the species seem to become more numerous. Many of them have smaller leaves than the modern species, others larger, and some have forms even more quaint than that of the existing Tulip tree. The oldest that I have seen in Canada is one from the Upper Cretaceous of

[1] Report on 49th Parallel, 1875.

Port McNeil in the north of Vancouver Island, which is as large as that of the modern species, and very similar in form. Thus this beautiful vegetable type culminated long geological ages ago, and was represented by many species, no doubt occupying a prominent place in the forests of the northern hemisphere. To-day only a single species exists, in our warmer regions, to keep up the memory of this almost perished genus ; but that species is one of our most beautiful trees.

The history of the Sequoias or giant Cypresses, of which two species now exist in limited areas in California, is still more striking. These giant trees, monsters of the vegetable kingdom, are, strange to say, very limited in their geographical range. The greater of the two, *Sequoia gigantea*, the giant tree *par excellence*, seems limited to a few groves in California. At first sight this strikes us as anomalous, especially as we find that the tree will grow somewhat widely both in Europe and America when its seeds are sown in suitable soil. The mystery is solved when we learn that the two existing species are but survivors of a genus once diffused over the whole northern hemisphere, and represented by many species, constituting, in the Later Cretaceous and Eocene ages, vast and dark forests extending over enormous areas of our continents, and forming much of the material of the thick and widely distributed Lignite beds of North-western America. Thus the genus has had its time of expansion and prevalence, and is now probably verging on extinction, not because there are not suitable habitats, but either because it is now old and moribund, or because other and newer forms have now a preference in the existing conditions of existence.

The Plane trees, the Sassafras, the curious Ginkgo tree or fern-leaved yew of Japan, are cases of similar decadence of genera once represented by many species, while other trees, like the Willows and Poplars, the Maples, the Birches, the Oaks and the Pines, though of old date, are still as abundant as

they ever were, and some genera would seem even to have increased in number of species, though on the whole the flora of our modern woods is much less rich than those of the Miocene and Eocene, or even than that of the Later Cretaceous. The early Tertiary periods were, as we know, times of exuberant and gigantic animal life on the land, and it is in connection with this that the vegetable world seems to have attained its greatest variety and luxuriance. Even that early post-glacial age in which primitive man seems first to have spread himself over our continents was one richer both in animal and plant life than the present. The geographical changes which closed this period and inaugurated the modern era seem to have reduced not only the area of the continents but the variety of land life in a very remarkable manner. Thus our last lesson from the genesis and migrations of plants is the humbling one that the present world is by no means the best possible in so far as richness of vegetable and animal life is concerned.

Reference has been made to the utility of fossil plants as evidence of climate; but the subject deserves more detailed notice. I have often pondered on the nature of the climate evidenced by the floras of the Devonian and Carboniferous; but the problem is a difficult one, not only because of the peculiar character of the plants themselves, so unlike those of our time, but because of the probably different meteorological conditions of the period. It is easy to see that a flora of tree-ferns, great lycopods and pines is more akin to that of oceanic islands in warm latitudes than anything else that we know. But the Devonian and Carboniferous plants did not flourish in oceanic islands, but for the most part on continental areas of considerable dimensions, though probably more flat and less elevated than those of the present day. They also grew, from Arctic latitudes, almost, if not altogether, to the equator; and though there are generic differences in the plants of these periods in

the southern hemisphere, yet these do not affect the general facies. There are, for example, characteristic Lepidodendroids in the Devonian and Carboniferous of Brazil, Australia, and South Africa. If now we consider the plants a little more in detail, coniferous and taxine trees grow now in very different latitudes and climates. There is therefore nothing so very remarkable in their occurrence. The great group of Cordaites may have been equally hardy; but it is noteworthy that their geographical distribution is more limited. In Europe, for example, they are more characteristic in France than in Great Britain. Ferns and Lycopods and Mares'-tails are also cosmopolitan, but the larger species belong to the warmer climates, and nowhere at present do they become so woody and so complex in structure as they were in the older geological periods. At the present day, however, they love moisture rather than aridity, and uniformity of temperature rather than extreme light and heat. The natural inference would be that in these older periods geographical and other conditions must have conspired to produce a uniform and moist climate over a large portion of the continents. The geographical conditions of the Carboniferous age, and the distribution of animal life on the sea and land, confirm the conclusion based on the flora. Further, if, as seems probable, there was a larger proportion of carbon dioxide in the atmosphere than at present, this would not only directly affect the growth of plants, but would impede radiation, and so prevent escape of heat by that means, while the moisture exhaled from inland seas and lagoons and vastly extended swamps, would tend in the same direction.

It would, however, be a mistake to infer that there were not local differences of climate. I have elsewhere [1] advocated the theory that the great ridge of boulders, the New Glasgow conglomerate, which forms one margin of the coal field of Picton,

[1] "Acadian Geology," Carboniferous of Picton.

in Nova Scotia, is an ice-formed ridge separating the area of accumulation of the great thirty-six feet seam from an outer area in which aqueous conditions prevailed, and little coal was formed. In this case, an ice-laden sea, carrying boulders on its floes and fields of ice, must have been a few miles distant from forests of Lepidodendra, Cordaites, and Sigillariæ, and the climate must have been anything but warm, at least at certain seasons. Nor have we a right to infer that the growth of the coal-plants was rapid. Stems, with woody axes and a thick bark, containing much fibrous and thick-walled cellular tissue, are not to be compared with modern succulent plants, especially when we consider the sparse and rigid foliage of many of them. Our conclusion should, therefore, be that geographical conditions and the abundance of carbon dioxide in the atmosphere favoured a moist climate and uniform temperature, and that the flora was suited to these conditions.

As to the early Mesozoic flora, I have already suggested that it must have been an invader from the south, for which the intervening Permian age had made way by destroying the Palæozoic flora. This was probably effected by great earth-movements changing geographical conditions. But in the Mesozoic the old conditions to some extent returned, and the Carboniferous plants being extinct, their places were taken by pines, lycopods, and ferns, whose previous home had been in the insular regions of the tropics, and which, as climatal conditions improved, pushed their way to the Arctic circle. But, being derivatives of warm regions, their vitality and capacity for variation were not great, and they only locally and in favourable conditions became great coal producers. The new flora of the Later Cretaceous and the Tertiary, as previously stated, originated in the Arctic, and marched southward.

These newer Cretaceous plants presented from the first the generic aspects of modern vegetation, and so enable us much better to gauge their climatal conditions. In general, they do

not indicate tropical heat in the far north, but only that of the warm temperate zone; but this in some portions of the period certainly extends to the middle of Greenland, unless, without any evidence, we suppose that the Cretaceous and lower Tertiary plants differed in hardiness of constitution from their modern representatives. They prove, however, considerable oscillations of climate. Gardner, Nathorst and Reid have shown this in Europe, and that it extends from the almost tropical flora of the lower Eocene to the Arctic flora of the Pleistocene. In America, owing, as Grey has suggested, to its great north and south extension, the changes were more regular and gradual. In the warmer periods of the Cretaceous, the flora as far north as 55° was similar to that of Georgia and Northern Florida at the present day, while in the cooler period of the Laramie (Lower Eocene, or more probably Paleocene) it was not unlike that of the Middle States. In the Pleistocene, the flora indicates a boreal temperature in the Glacial age. Thus there are no very extreme contrasts, but the evident fact of a warm temperate or sub-tropical climate extending very far north at the same times when Greenland had a temperate climate. As I have elsewhere shown,[1] discoveries in various parts of North America are beginning to indicate the precise geographical conditions accompanying the warmer and colder climates.

It would be wrong to leave this subject without noticing that remarkable feature in the southward movement of the later floras, to which I believe Prof. Gray was the first to direct attention. In those periods when a warm climate prevailed in the Arctic regions, the temperate flora must have been, like the modern Arctic flora, circumpolar. When obliged to migrate to the south, it had to follow the lines of the continents, and so to divide into separate belts. Three of these at present are the floras of Western Europe, Eastern Asia, and Eastern America, all of which have many representative

[1] Trans. Royal Society of Canada, 1890–1.

species. They are separated by oceans and by belts of land occupied by plants which have not been obliged to migrate. Thus, while the flora of the Eastern United States resembles that of China and Japan, that of California and Oregon is distinct from both, and represents a belt of old species retained in place by the continued warmth of the Pacific shore, and the continuous extension of the American continent to the south affording them means of retreat in the Glacial age. Were the plants of China and Eastern America enabled to return to the Arctic, they would then reunite into one flora. Gray compares the process of their separation to the kind of selection which might be made by a botanical distributor who had the whole collection placed in his hands, with instructions to give one species of each genus to Europe, to Eastern Asia, and to Eastern America; and if there was only one species in a genus, or if one remained over, this was to be thrown into one of the regions, with a certain preference in favour of America and Asia. This remarkable kind of geographical selection opens a wide field not only for thought, but for experiment on the actual relationship of the representative species. There is a similar field for comparison between the trees of Georgia in latitude 30° to 35°, and the same species or their representatives as they existed in Cretaceous times in the latitudes of 50° and 60°. The two floras, as I know from actual comparison, are very similar.

One word may be said here as to use of fossil plants in determining geological time. In this I need only point to the fact of my having defined in Canada three Devonian floras, a Lower, Middle, and Upper, and that Mr. Whiteaves, in his independent study of the fossil fishes, has vindicated my conclusions. There are also in Nova Scotia three distinctive sub-floras of the Lower, Middle, and Upper Carboniferous.[1] I

[1] Transactions Royal Society of Canada, 1883 to 1891.

have verified these for the Devonian and Carboniferous of the United States, and to some extent also for those of Europe. To the same effect is the recognition of the Kootanie or Lower Cretaceous, the Middle Cretaceous, Upper Cretaceous, Laramie and Miocene in Western Canada. These have in all cases corresponded with the indications of animal fossils[1] and of stratigraphy. Fossil plants have been less studied in this connection than fossil animals, but I have no hesitation in affirming that, with reference to the broader changes of the earth's surface, any competent palæobotanist is perfectly safe in trusting to the evidence of vegetable fossils.

It may be objected that such evidence will be affected by the migrations of plants, so that we cannot be certain that identical species flourished in Greenland and in temperate America at the same time. If such species originated in Greenland and migrated southward, the specimens found at the south may be much newer than those in the north. This, no doubt, is locally true, but the migrations of plants, though slow, occupy less time than that of a great geological period. It may also be objected that the flora of swamps, plains, and mountain tops would differ at any one period. This also is true, but the same difficulty applies to animals of the deep sea, the shore, and the land; and these diversities of station have always to be taken into account by the palæontologist.

REFERENCES:—Report on the Erian or Devonian Plants of Canada, Montreal, 1871. Article in *Princeton Review* on Genesis and Migrations of Plants. "The Geological History of Plants," London and New York, 1888 and 1892. Papers on Fossil Plants of Western Canada, 1883, and following volumes of Transactions of Royal Society of Canada.

NOTE.—Since writing the above, I have obtained access to Dall and Harris' "Neocene Correlation Papers," which throw some additional

[1] Reports on Fossil Plants of the Devonian and Lower Carboniferous.

light on the Cretaceous and Eocene Floras of Alaska, which, from its high northern latitude, affords a good parallel to Greenland. It would appear that plant beds occur in that territory at two horizons. One of these (Cape Beaufort), according to Lesquereux and Ward, holds species of Neocomian Age, and apparently equivalent to the Kootanie of British Columbia and the Komé of Greenland. The other, which occurs at several localities (Elukak, Port Graham, etc.), has a flora evidently of Laramie (Eocene) age, equivalent to the "Miocene" of Heer and Lesquereux, and to the Lignite Tertiary of Canada. The plants are accompanied by lignite, and evidently *in situ*, and clearly prove harmony with Greenland and British Columbia in two of the periods of high Arctic temperature indicated above.

THE GROWTH OF COAL.

DEDICATED TO THE MEMORY OF

DR. SCHIMPER,

OF STRASBURG,

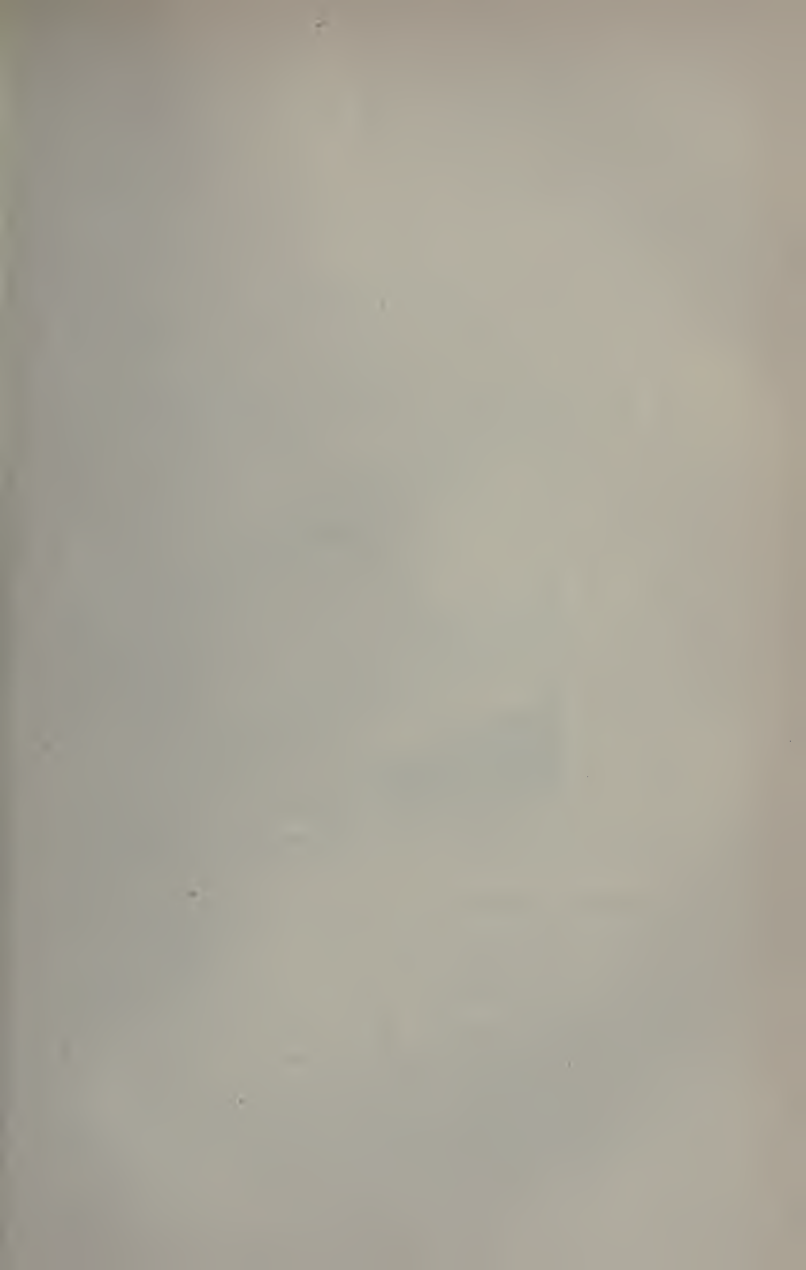
THE AUTHOR OF "LA FLORE DU MONDE PRIMITIF," AND MANY OTHER CONTRIBUTIONS TO FOSSIL BOTANY,

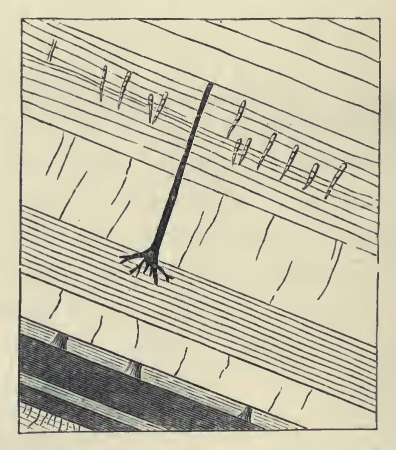
AND OF

DR. H. R. GOEPPERT,

WHOSE ESSAY ON THE STRUCTURE AND FORMATION OF COAL WAS ONE OF MY FIRST GUIDES IN ITS STUDY.

Questions of Growth and Driftage—Testimony of a Block of Coal under the Microscope—Different Kinds of Coal—Conditions Necessary to Accumulation in situ—Coal Beds and their Accompaniments—Underclays and Roofs—Vegetable Remains—History of Coal Groups—Summary of Evidence—Subsidence of Coal Areas—Stigmaria and other Coal Plants—Later Coal Accumulations—The Story and Uses of Coal





PART OF A COAL GROUP, at the South Joggins, with underclays and erect trees and Calamites (p. 238).

CHAPTER IX.

THE GROWTH OF COAL.

MY early boyhood was spent on the Coal formation rocks and in the vicinity of collieries; and among my first natural history collections, in a childish museum of many kinds of objects, were some impressions of fern leaves from the shales of the coal series. It came to pass in this way that the Carboniferous rocks were those which I first studied as an embryo geologist, and much of my later work has consisted in collecting and determining the plants of that ancient period, and in studying microscopic sections of coals and fossil woods accompanying them. For this reason, and because I have published so much on this subject, my first decision was to leave it out of these Salient Points: but on second thoughts it seemed that this might be regarded as a dereliction of duty; more especially as some of the conclusions supposed to be the best established on this subject have recently been called in question.

Had I been writing a few years ago, I might have referred to the mode of formation of coal as one of the things most surely settled and understood. The labours of many eminent geologists, microscopists and chemists in the old and the new worlds had shown that coal nearly always rests upon old soil-surfaces penetrated with roots, and that coal beds have in their roofs erect trees, the remains of the last forests that grew upon them. Logan and the writer have illustrated this in the case of the series of more than eighty successive coal beds exposed at the

South Joggins, and of the great thirty feet seam of the Picton coal series, whose innumerable laminæ have all been subjected to careful scrutiny, and have shown unequivocal evidence of land surfaces accompanying the deposition of the coal. Microscopical examination has proved that these coals are composed of the materials of the same trees whose roots are found in the underclays, and their stems and leaves in the roof shales; that much of the material of the coal has been partially subjected to subaërial decay at the time of its accumulation; and that in this, ordinary coal differs from bituminous shale, earthy bitumen and some kinds of cannel, which have been formed under water; that the matter remaining as coal consists almost entirely of epidermal tissues, which being suberose or corky in character are highly carbonaceous, very durable and impermeable by water, and are, hence, the best fitted for the production of pure coal; and finally, that the vegetation and the climatal and geographical features of the coal period were eminently fitted to produce in the vast swamps of that period precisely the effects observed. All these points and many others have been thoroughly worked out for both European and American coal fields, and seemed to leave no doubt on the subject. But several years ago certain microscopists observed in slices of coal, thin layers full of spore cases, a not unusual circumstance, since these were shed in vast abundance by the trees of the coal forests, and because they contain suberose matter of the same character with epidermal tissues generally. Immediately we were informed that all coal consists of spores, and this being at once accepted by the unthinking, the results of the labours of many years are thrown aside in favour of this crude and partial theory. A little later, a German microscopist has thought proper to describe coal as made up of minute algæ, and tries to reconcile this view with the appearances, devising at the same time a new and formidable nomenclature of generic and specific names, which would seem largely to represent mere

fragments of tissues. Still later, some local facts in a French coal field have induced an eminent observer of that country to revive the drift theory of coal, in opposition to that of growth *in situ*. Views of this kind have also recently been advanced in England by some of those younger men who would earn distinction rather by overthrowing the work of their seniors than by building on it. These writers base their conclusions on a few exceptional facts, as the occasional occurrence of seams of coal without distinct underlays, and the occurrence of clay partings showing aquatic conditions in the substance of thick coals ; and they fail to discern the broader facts which these exceptions confirm. Let us consider shortly the essential nature of coal, and some of the conditions necessary to its formation.

A block of the useful mineral which is so important an element in national wealth, and so essential to the comfort of our winter homes, may tell us much as to its history if properly interrogated, and what we cannot learn from it alone we may be taught by studying it in the mine whence it is obtained, and in the cliffs and cuttings where the edges of the coaly beds and their accompaniments are exposed.

Our block of coal, if anthracite, is almost pure carbon. If bituminous coal, it contains also a certain amount of hydrogen, which in combination with carbon enables it to yield gas and coal tar, and which causes it to burn with flame. If, again, we examine some of the more imperfect and more recent coals, the brown coals, so called, we shall find that in composition and texture they are intermediate between coal proper and hardened or compressed peat. Now such coaly rocks can, under the present constitution of nature, be produced only in one way, namely, by the accumulation of vegetable matter, for vegetation alone has the power of decomposing the carbonic acid of the atmosphere, and accumulating it as carbon. This we see in modern times in the vegetable soil, in peaty beds, and in

vegetable muck accumulated in ponds and similar places. Such vegetable matter, once accumulated, requires only pressure and the changes which come of its own slow putrefaction to be converted into coal.

But in order that it may accumulate at all, certain conditions are necessary. The first of these includes the climatal and organic arrangements necessary for abundant vegetable growth. The second is the facility for the preservation of the vegetable matter, without decay or intermixture with earthy substances; and this, for a long time, till a great thickness of it accumulates. The third is its covering up by other deposits, so as to be compressed and excluded from air. It is evident that when we have to consider the formation of a bed of coal several feet in thickness, and spread, perhaps, over hundreds of square miles, many things must conduce to such a result, and the wonder is perhaps rather that such conditions should ever have been effectively combined. Yet this has occurred at different periods of geological history and in many places, and in some localities it has been so repeated as to produce many beds of coal in succession.

Let us now question our block of coal as to its origin, supposing it to be a piece of ordinary bituminous coal, or still better, a specimen of one of the impure somewhat shaly coals which one sometimes finds accidentally in the coal bin. In looking at the edge of our specimen we observe that it has a "reed" or grain, which corresponds with the lamination or bedding of the seam of coal from which it came. Looking at this carefully, we shall see that there are many thin layers of bright shining coal, and the more of these usually the better the coal. These layers, in tracing them along, we observe often to thin out and disappear. They are not very continuous. If our specimen is an impure coal, we will find that it readily splits along the surfaces of these layers, and that when so split, we can see that each layer of shining coal has certain markings, perhaps the flattened

ribs and scars of Sigillaria or other coal-formation trees on its surface. In other words, the layers of fine coal are usually flattened trunks and branches of trees, or perhaps rather of the imperishable and impermeable bark of such trees, the wood having perished. A few very thin layers of shining coal we may also find to consist of the large-ribbed leaves of the plant known as Cordaites. This kind of coaly matter then usually represents trunks of trees which in a prostrate and flattened state may constitute more than half of the bulk of ordinary coal-formation coal. Under the microscope this variety of coal shows little structure, and this usually the thickened cells of cortical tissue. Intervening between these layers we perceive laminæ, more or less thick and continuous, of what we may call dull coal, black but not shining; resembling, in fact, the appearance of cannel coal. If we split the coal along one side of these layers, and examine it in a strong light, we may see shreds of leaf stalks and occasionally even of fern leaves, or skeletons of these, showing the veins, and many flattened disc-like bodies, spore cases and macrospores, shed by the plants which make up the coal. These layers represent what may be called compressed vegetable mould or muck, and this is by no means a small constituent of many coals. This portion of the coal is the most curious and interesting in microscopic slices, showing a great variety of tissues and many spores and spore cases. Lastly, we find on the surface of the coal, when split parallel to the bedding, a quantity of soft shining fibrous material, known as mineral charcoal or mother coal, which in some varieties of the mineral is very abundant, in others much more rare. This is usually too soft and incoherent to be polished in thin slices for the microscope; but if boiled for a length of time in nitric acid, so as to separate all the mineral matter contained in it, the fibres sometimes become beautifully translucent and reveal the tissues of the wood of various kinds of Carboniferous trees, more especially of Calamites, Cordaites and Sigillariæ. Fibres

of mineral charcoal prepared in this way are often very beautiful microscopic objects under high powers; and this material of the coal is nothing else than little blocks of rotten wood and fibrous bark, broken up and scattered over the surface of the forming coal bed. All these materials, it must be observed, have been so compressed that the fragments of decayed wood have been flattened into films, the vegetable mould consolidated into a stony mass, and trunks of great trees converted by enormous pressure into laminæ of shining coal, a tenth of an inch in thickness, so that the whole material has been reduced to perhaps one-hundredth of its original volume.

Restoring the mass in imagination to its original state, what do we find? A congeries of prostate trunks with their interstices filled with vegetable muck or mould, and occasional surfaces where rotten wood, disintegrated into fragments, was washed about in local floods or rain storms, and thus thrown over the surface. Lyell seems very nearly to have hit the mark when he regarded the conditions of the great dismal swamp of Virginia as representing those of a nascent coal field. We have only to realize in the coal period the existence of a dense vegetation very different from that of modern Virginia, of a humid and mild climate, and of a vast extension of low swampy plains, to restore the exact conditions of the coal swamps.

But how does this correspond with the facts observed in mines and sections? To the late Sir William Logan is due the merit of observing that in South Wales the underclays or beds of indurated clay and earth underlying the coal seams are usually filled with the long cylindrical rootlets and branching roots of a curious plant, very common in the coal formation, the Stigmaria. He afterwards showed that the same fact occurs in the very numerous coal beds exposed in the fine section cut by the tides of the Bay of Fundy, in the coal rocks of Nova Scotia. In that district I have myself followed up

his observations, examining in detail every one of eighty-one Coal Groups, as I have called them, each consisting of at least one bed of coal, large or small, with its accompaniments, and in many cases of several small seams with intervening clays or shales.[1] In nearly every case the Stigmaria "under-clay" is distinctly recognisable, and often in a single coal group there are several small seams separated by underclays with roots and rootlets. These underclays are veritable fossil soils; sometimes bleached clays or sands, like the subsoils of modern swamps; sometimes loamy or sandy, or of the nature of hardened vegetable mould. They rarely contain any remains of aquatic animals, or of animals of any kind, but are filled with stigmaria roots and rootlets, and sometimes hold a few prostrate stems of trees.[2] While the underclay is thus a fossil soil, the roof or bed above the coal, usually of a shaly character, is full of remains of leaves and stems and fruits, and often holds erect stumps, the remains of the last trees that grew in the swamp before it was finally covered up.

Some of the thinnest coals, and some beds so thin and impure that they can scarcely be called coals at all, are the most instructive. Witness the following from my section of the South Joggins.

Coal Group 1, of Division 3, is the highest of the series. Its section is as follows:—

"Grey argillaceous shale.
Coal, 1 inch.
Grey argillaceous underclay, Stigmaria.

"The roof holds abundance of fern leaves (*Alethopteris*

[1] For details see *Journal Geol. Society of London*, 1865; and "Acadian Geology," last edition, 1891.

[2] At the South Joggins, in two or three cases, beds of bituminous shale full of Naiadites and Cyprids have by elevation and drying become fit for the growth of trees with stigmaria roots; but this is quite exceptional, no doubt arising from the accidental draining of lakes or lagoons on their elevation above the sea level.

lonchitica). The coal is coarse and earthy, with much epidermal and bast tissue, spore cases, etc., vascular bundles of ferns and impressions of bark of Sigillaria and leaves of Cordaites. It may be considered as a compressed vegetable soil resting on a subsoil full of rootlets of Stigmaria." In this case the coal is an inch in thickness, but there are many beds where the coal is a mere film, and supports great erect stems of Sigillaria, sending downward their roots in the form of branching Stigmariæ into the underclay, thus proving that the Stigmariæ of the underclays are the roots of the Sigillariæ of the coals and their roofs.

Here is another example which may be called a coal group, and is No. 11 of the same division:

"Grey argillaceous shale, erect Calamites.
Coal, 1 inch.
Grey argillaceous underclay, Stigmaria, 1ft. 6in.
Coal, 2 inches.
Grey argillaceous underclay, Stigmaria, 4 in.
Coal, 1 inch.
Grey argillaceous underclay, Stigmaria.

"This is an alternation of thin, coarse coals with fossil soils. The roof shale contains erect Calamites, which seem to have been the last vegetation which grew on the surface of the upper coal."

Such facts, with many minor varieties, extend through the whole eighty-one coal groups of this remarkable section, as any one may see by referring to the paper and work cited in the preceding note. It is possibly because in most coal fields the smaller and commercially useless beds are so little open to observation, that so crude ideas derived merely from imperfect access to the beds that are worked exist among geologists. The following summary of facts may perhaps serve to place the evidence as to the mode of accumulation of coal fairly before the reader:—

(1) The occurrence of Stigmaria under nearly every bed of coal proves, beyond question, that the material was accumulated by growth *in situ*, while the character of the sediments intervening between the beds of coal proves with equal certainty the abundant transport of mud and sand by water. In other words, conditions similar to those of the swampy deltas of great rivers, or the swampy flats of the interiors of great continents, are implied.

(2) The true coal consists principally of the flattened bark of sigillaroid and other trees, intermixed with leaves of ferns and *Cordaites*, and other herbaceous *débris*, including vast numbers of spores and spore cases, and with fragments of decayed wood constituting "mineral charcoal," all their materials having manifestly alike grown and accumulated where we find them.

(3) The microscopical structure and chemical composition of the beds of cannel coal and earthy bitumen, and of the more highly bituminous and carbonaceous shales, show them to have been of the nature of the fine vegetable mud which accumulates in the ponds and shallow lakes of modern swamps. These beds are always distinct from true subaërial coal. When such fine vegetable sediment is mixed, as is often the case, with mud, it becomes similar to the bituminous limestone and calcareo-bituminous shales of the coal measures.

(4) A few of the underclays which support beds of coal are of the nature of the vegetable mud above referred to; but the greater part are argillo-arenaceous in composition, with little vegetable matter, and bleached by the drainage from them of water containing the products of vegetable decay. They are, in short, loamy or clay soils in the chemical condition in which we find such soils under modern bogs, and must have been sufficiently above water to admit of drainage. The absence, or small quantity of sulphides, and the occurrence of carbonate of iron in connection with them, prove that

when they existed as soils, rain water, and not sea water, percolated them.

(5) The coal and the fossil trees present many evidences of subaërial conditions. Most of the erect and prostrate trees had become hollow shells of bark before they were finally imbedded, and their wood had broken into cubical pieces of mineral charcoal. Land snails and galley worms (*Xylobius*) crept into them, and they became dens or traps for reptiles. Large quantities of mineral charcoal occur on the surfaces of all the larger beds of coal. None of these appearances could have been produced by subaqueous action.

(6) Though the roots of *Sigillaria* bear some resemblance to the rhizomes of certain aquatic plants, yet structurally they have much resemblance to the roots of Cycads, which the stems also resemble. Further, the *Sigillariæ* grew on the same soils which supported conifers, *Lepidodendra*, *Cordaites*, and ferns, plants which could not have grown in water. Again, with the exception, perhaps, of some *Pinnulariæ* and *Asterophyllites*, and Rhizocarpean spores, there is a remarkable absence from the coal measures of any form of properly aquatic vegetation.

(7) The occasional occurrence of marine or brackish-water animals in the roofs of coal beds, or even in the coal itself, affords no evidence of subaqueous accumulation, since the same thing occurs in the case of modern submarine forests. Such facts merely imply that portions of the areas of coal accumulation were liable to inundation of a character so temporary as not finally to close the process, as happened when at last a roof shale was deposited by water over the coal. Cannel coals and bituminous shales holding mussel-like shells, fish scales, etc., imply the existence sometimes for long periods of ponds, lakes or lagoons in the coal swamps, but ordinary coal did not accumulate in these. It is in the cannels and similar subaqueous coals that the macrospores which I

attribute in great part to aquatic plants, allied to modern Salvinia, etc., are chiefly found.[1]

For these and other reasons, some of which are more fully stated in the papers referred to, while I admit that the areas of coal accumulation were frequently submerged, I must maintain that the true coal is a subaërial accumulation by vegetable growth on soils wet and swampy, it is true, but not submerged. I would add the further consideration, already urged elsewhere, that in the case of the fossil forests associated with the coal, the conditions of submergence and silting-up which have preserved the trees as fossils, must have been precisely those which were fatal to their existence as living plants, a fact sufficiently evident to us in the case of modern submarine forests, but often overlooked by the framers of theories of the accumulation of coal.

It seems strange that the occasional inequalities of the floors of the coal beds, the sand or gravel ridges which traverse them, the channels cut through the coal, the occurrence of patches of sand, and the insertion of wedges of such material splitting the beds, have been regarded by some able geologists as evidences of the aqueous origin of coal. In truth, these appearances are of constant occurrence in modern swamps and marshes, more especially near their margins, or where they are exposed to the effects of ocean storms or river inundations. The lamination of the coal has also been adduced as a proof of aqueous deposition; but the miscroscope shows, as I have elsewhere pointed out, that this is entirely different from aqueous lamination, and depends on the superposition of successive generations of more or less decayed trunks of trees and beds of leaves. The lamination in the truly aqueous cannels and carbonaceous shales is of a very different character.

It is scarcely necessary to remark that in the above summary

[1] "Geological History of Plants," *Bulletin Chicago Academy of Sciences*, 1886.

I have had reference principally to my own observations in the coal formation of Nova Scotia; but similar facts have been detailed by many other observers in other districts.[1]

A curious point in connection with the origin of coal is the question how could vegetable matter be accumulated in such a pure condition? There is less difficulty in regard to this if we consider the coal as a swamp accumulation *in situ*. It is in this way that the purest vegetable accumulations take place at present, whereas in lakes and at the mouths of rivers vegetable matter is always mixed up with mud. Coal swamps, however, must have been liable to submergences or to temporary inundations, and it is no doubt to these that we have to attribute the partings of argillaceous matter often found in coal beds, as well as the occasional gulches cut into the coal and filled with sand and lenticular masses of earthy matter. To a similar cause we must also attribute the association of cannel with ordinary coal. The cannel is really a pulpy, macerate mass of vegetable matter accumulated in still water, surrounded and perhaps filled with growing aquatic herbage. Hence it is in such beds that we find the greatest accumulations of macrospores, derived, probably, in great part from aquatic plants. Buckland long ago compared the matter of cannel to the semifluid discharge of a bursting bog, and Alex. Agassiz has more recently shown that in times of flood the vegetable muck of the Everglades of Florida flows out in thick inky streams, and may form large beds of vegetable matter having the character of the materials of cannel. It is evident that in swamps of so great extent as those of the coal formation, there must have been shallow lakes and ponds, and wide sluggish streams, forming areas for the accumulation of vegetable *débris* and this readily accounts for the association of ordinary beds of coal with those of cannel, and with bituminous shales or

[1] Especially Brongniart, Goeppert, Hawkshaw, Lyell, Logan, De la Boche, Beaumont, Binney, Rogers, Lesquereux, Williamson, Grand' Eury.

earthy bitumen, as well as for the occurrence of scales of fish and other aquatic animals in such beds. Lyell's interesting observation of the submerged areas at New Madrid, keeping free of Mississippi mud, because fringed with a filter of cane-brake, shows that the areas of coal accumulation might often be inundated without earthy deposit, if, as seems probable, they were fringed with dense brakes of calamites, sheltering them from the influx of muddy water. It seems also certain that the water of the coal areas would be brown and laden with imperfect vegetable acids, like that of modern bogs, and such water has usually little tendency to deposit any mineral matter, even in the pores of vegetable fragments. The only exception to this is one which also occurs in modern swamps, namely, the tendency to deposit iron, either as carbonate (Clay Ironstone), or sulphide (Iron Pyrite), both of which are products of modern bogs, and equally characteristic of the coal swamps.

Where great accumulations of sediment are going on, as at the mouths of modern rivers, there is a tendency to subsidence of the area of the deposit, owing to its weight. This applies, perhaps, to a greater extent to coal areas. Thus the area of a coal swamp would ultimately sink so low as to be overflowed, and a roof shale would be deposited to bury up the bed of coal, and transmit it to future ages, chemically, and mechanically changed by pressure and by that slow decomposition which gradually converts vegetable matter into carbon and hydrocarbons. The long continuance and great extent of these alternations of growth and subsidence is perhaps the most extraordinary fact of all. At the South Joggins, if we include the surfaces having erect trees with those having beds of coal, the process of growth of a forest or bog, and its burial by subsidence and deposition must have been repeated about a hundred times before the final burial of the whole under the thick sandstones of the Upper Carboniferous and Permian.

Mention has been made of Sigillaria and other trees of the coal formation period. These trees and others allied to them, of which there were many kinds, may be likened to gigantic club mosses, which they resembled in fruit and foliage, though vastly more complex in structure of stem and branch. Some of them, perhaps, were of much higher rank than any of the modern plants most nearly allied to them. One of their most remarkable features was that of their roots—those Stigmariæ, to which so frequent reference has been made. They differed from modern roots, not only in some points of structure, but in their regular bifurcation, and in having huge root fibres articulated to the roots, and arranged in a regular spiral manner, like leaves. They radiate regularly from a single stem, and do not seem to have sent up buds or secondary stems. They thus differed from the botanical definition of a root, and also from that of a rhizoma, or root stock; being, in short, a primitive and generalized contrivance, suited to trees themselves primitive and generalized, and to special and peculiar circumstances of growth. Some botanists have imagined that they were aquatic plants, growing at the bottom of lakes, but their mode of occurrence negatives this. I have elsewhere stated this as follows:—[1]

"It is quite certain that Stigmariæ are not 'rhizomes which floated in water, or spread themselves out on the surface of mud.' Whether rhizomes or not, they grew in the soil, or in the upper layers of peaty deposits since changed into coal. The late Richard Brown and the writer have shown that they grew in the underclays or fossil soils, and that their rootlets radiated in these soils in all directions.[2] In one of my papers I have figured a Stigmarian root penetrating through an erect *Sigillaria*, and Logan, in his Report of 1845, had already

[1] *Natural Science*, May, 1892.

[2] *Quart. Journ. Geol. Soc.*, vol. ii. p. 394 (1846); *Ibid.*, vol. iv. p. 47 (1847); *Ibid.*, vol. v. p. 355 (1849); *Ibid.*, vol. v. pp. 23, 30.

figured a similar example. The penetration of decaying stems by the rootlets of *Stigmaria* is a fact well known to all who have studied slices of Carboniferous plants,[1] while Stigmariæ are often found creeping inside the bark of erect and prostrate trunks. Besides this, as I have shown in 'Acadian Geology,' in the section of 5,000 feet of coal measures at the South Joggins (including eighty-one distinct coal groups, and a larger number of soils with *Stigmaria*, or erect trees), *Sigillaria* and *Stigmaria* occur together, and the latter nearly always either in argillaceous soils, or sands hardened into 'Gannister,' which are often filled with roots or rootlets, or on the surfaces of coal beds. On the other hand, the numerous bituminous limestones, and calcareous and other shales holding remains of fishes, crustaceans, and bivalve shells do not contain Stigmaria *in situ*—the only exceptions being two beds of bituminous limestone, the upper parts of which have been converted into underclays. This section, and that of North Sydney—two of the most complete and instructive in the world—have afforded conclusive proof of this mode of growth of *Sigillaria* and *Stigmaria*.

"The objection to calling the Stigmariæ roots and their processes rootlets, appears to me a finical application of modern botanical usages to times for which they do not hold. We might equally object to the application of the term roots to those which spring from the earthed-up stems of Calamites, radiating as they do from nodes which, in the air, would produce branchlets. Grand' Eury's figures show abundant instances of this. We might also object to the exogenous stems described by Williamson, which belong to cryptogamous plants; and, unlike anything modern, are made up exclusively of scalariform tissue. If the articulation and regular arrangement of those gigantic root hairs, the rootlets, or 'leaves' of

[1] Williamson has noticed this in his excellent Memoirs in the *Phil. Trans.*

Stigmaria, are to be regarded as depriving them of the name which clearly describes their function, we may call them underground branches, though, by so doing, we set at nought both their function and their mode of growth."

Dr. Williamson, in a recent paper, expresses the same view in the following terms [1] :—" At that period (the Carboniferous age) no Angiosperms existed on the earth, and even the Gymnosperms were very far from reaching their modern development. Under these circumstances the Cryptogams chiefly became the giant forest trees of that remote age. To become such, they required an organization very different in some respects from that of their degraded living representatives. Hence we must not appeal to these degenerate types for illustrations and explanations of structures no longer existing. Still less must we turn to what we find in the Angiosperms, that wholly distinct race which has taken the place of the primæval Cryptogams in our woods. The primæval giants of the swampy forests had doubtless a morphology assigned to them, adapted to the physical conditions by which they were surrounded; but if even their dwarfed and otherwise modified descendants fail to throw light upon morphological details once so common, still less must we expect to obtain that light from the living and wholly different flowering plants."

With the remarkable trees above referred to, there co-existed a vast multitude of ferns, some arborescent, others herbaceous, tall, reed-like plants, the Calamites, allied to modern Mares'-tails, a very remarkable family of plants allied to modern Cycads and Pines; the Cordaites, which seem to have grown plentifully in certain parts of the coal areas—probably the drier parts, so that their remains sometimes constitute the greater part of small seams of coal. There were also true pine-like trees, though these would seem to have grown most abun-

[1] *Natural Science*, July, 1892.

dantly on the higher levels. Nor was strictly aquatic vegetation wanting. We find, both in the preceding Devonian and the Carboniferous, that the little aquatic plants now known as Rhizocarps, and structurally allied to the Ferns—such plants as the floating Salvinia, and the Pillworts of our swamps, were vastly abundant, and they may have filled and choked up with their exuberant growth many of the lakes and slow streams of the period, furnishing layers of cannel and "macrospore" coal, and earthly bitumen or Torbanite.

We have hitherto confined our attention to the great Carboniferous period, so called, as emphatically the age of coal; but this mineral, and allied forms of carbon, were produced both before and after. Even in that old Laurentian age, which includes the oldest rocks that we know, formed when the first land had just risen out of the waters, there are thick beds of graphite, or plumbago, chemically the same with anthracite coal, and which must have been produced by the agency of plants, whether terrestrial or aquatic. We may suppose that the plants of this remote age were of very humble type as much lower than those of the coal formation as these are lower than those of the present day; but if so, then, on the analogy of the Carboniferous, they would be high and complex representatives of those low types. But there is another and more startling possibility; that the Laurentian may have been a period when vegetable life culminated on the earth, and existed in its most complete and grandest forms in advance of the time when it was brought into subordination to the higher life of the animal. In the meantime, the Laurentian rocks are in a state of so extreme metamorphism that they have afforded no certain indication of the forms or structures of the vegetation of the period.

We find indications of plant life through all the Palæozoic groups succeeding the Laurentian; but it is not till we reach the Devonian, the system immediately preceding the Carboni-

ferous, that we find an abundance of forms not essentially different from those of the Carboniferous, though similar in details. Only a few and very small beds of coal were accumulated in this age; but there was an immense abundance of bituminous shale enriched with the macrospores of Rhizocarps. The Ohio black shale, which is said to extend its outcrop across that state with a breadth of ten to twenty miles, and a thickness of 550 feet, is filled with macrospores of Protosalvinia, as is its continuation in Canada.

Above the great coal formation the Permian and Jurassic contain beds of coal, though of limited extent, and formed in the case of the two latter of very different plants from those of the Carboniferous. In the Cretaceous and Tertiary ages, after the abundant introduction of species of forest trees still living, coal making seems to have obtained a new impulse, so that in China and the western part of America there are coals of great extent and value, all made of plants of genera still existing. In the Cretaceous coal of Vancouver Island there are remains of such modern trees as the Poplars, Magnolias, Palmettos, Sequoias, and a great variety of other genera still living in America. Out of the remains of these, under favouring conditions, quite as good coal as that of the coal formation has been made, although the plants are so different. There is, indeed, reason to believe that those now rare trees, the Sequoias, represented at the present time only by the big trees of California, and their companion, the redwood, were then spread universally over the northern hemisphere, and formed dense forests on swampy flats which led to the accumulation of coal beds in which the trunks and leaves of the Sequoias formed main ingredients, so that Sequoia and its allies in this later age take the place of the Sigillariæ of the coal formation. Last of all, coal accumulation is still going on in the Everglades of Florida, the dismal swamp of Virginia, and the peat-bogs of the more northern regions. So the vegetable kingdom

has, throughout its long history, been continually depriving the atmosphere of its carbon dioxide, and accumulating this in beds of coal. In the earlier ages indeed, this would seem to us to have been its main use.

To the modern naturalist, vegetable life, with regard to its uses, is the great accumulator of pabulum for the sustenance of the higher forms of vital energy manifested in the animal. In the Palæozoic this consideration sinks in importance. In the Coal period we know few land animals, and these not vegetable feeders, with the exception of some insects, millipedes, and snails. But the Carboniferous forests did not live in vain, if their only use was to store up the light and heat of those old summers in the form of coal, and to remove the excess of carbonic acid from the atmosphere. In the Devonian period even these utilities fail, for coal does not seem to have been accumulated to any great extent, though the abundant petroleum of the Devonian is, no doubt, due to the agency of aquatic vegetation. In addition to scorpions, a few insects are the only known tenants of the Devonian land, and these are of kinds whose larvæ probably lived in water, and were not dependent on land plants. We may have much yet to learn of the animal life of the Devonian; but for the present, the great plan of vegetable nature goes beyond our measures of utility; and there remains only what is perhaps the most wonderful and suggestive correlation of all, namely, that our minds are able to trace in these perished organisms structures similar to those of modern plants, and thus to reproduce in imagination the forms and habits of growth of living things which so long preceded us on the earth.

In another way Huxley has put the utilitarian aspect of the case so admirably, that I cannot refrain from quoting his clever apotheosis of nature in connection with the production of coal.

"Nature is never in a hurry, and seems to have had always before her eyes the adage, 'Keep a thing long enough, and

you will find a use for it.' She has kept her beds of coal for millions of years without being able to find a use for them; she has sent them beneath the sea, and the sea beasts could make nothing of them; she had raised them up into dry land, and laid the black veins bare, and still for ages and ages there was no living thing on the face of the earth that could see any sort of value in them; and it was only the other day, so to speak, that she turned a new creature out of her workshop, who, by degrees, acquired sufficient wits to make a fire, and then to discover that the black rock would burn.

"I suppose that nineteen hundred years ago, when Julius Cæsar was good enough to deal with Britain as we have dealt with New Zealand, the primæval Briton, blue with cold and woad, may have known that the strange black stone which he found here and there in his wanderings would burn, and so help to warm his body and cook his food. Saxon, Dane, and Norman swarmed into the land. The English people grew into a powerful nation; and Nature still waited for a return for the capital she had invested in ancient club mosses. The eighteenth century arrived, and with it James Watt. The brain of that man was the spore out of which was developed the steam engine, and all the prodigious trees and branches of modern industry which have grown out of this. But coal is as much an essential of this growth and development as carbonic acid is of a club moss. Wanting the coal, we could not have smelted the iron needed to make our engines; nor have worked our engines when we got them. But take away the engines, and the great towns of Yorkshire and Lancashire vanish like a dream. Manufactures give place to agriculture and pasture, and not ten men could live where now ten thousand are amply supported.

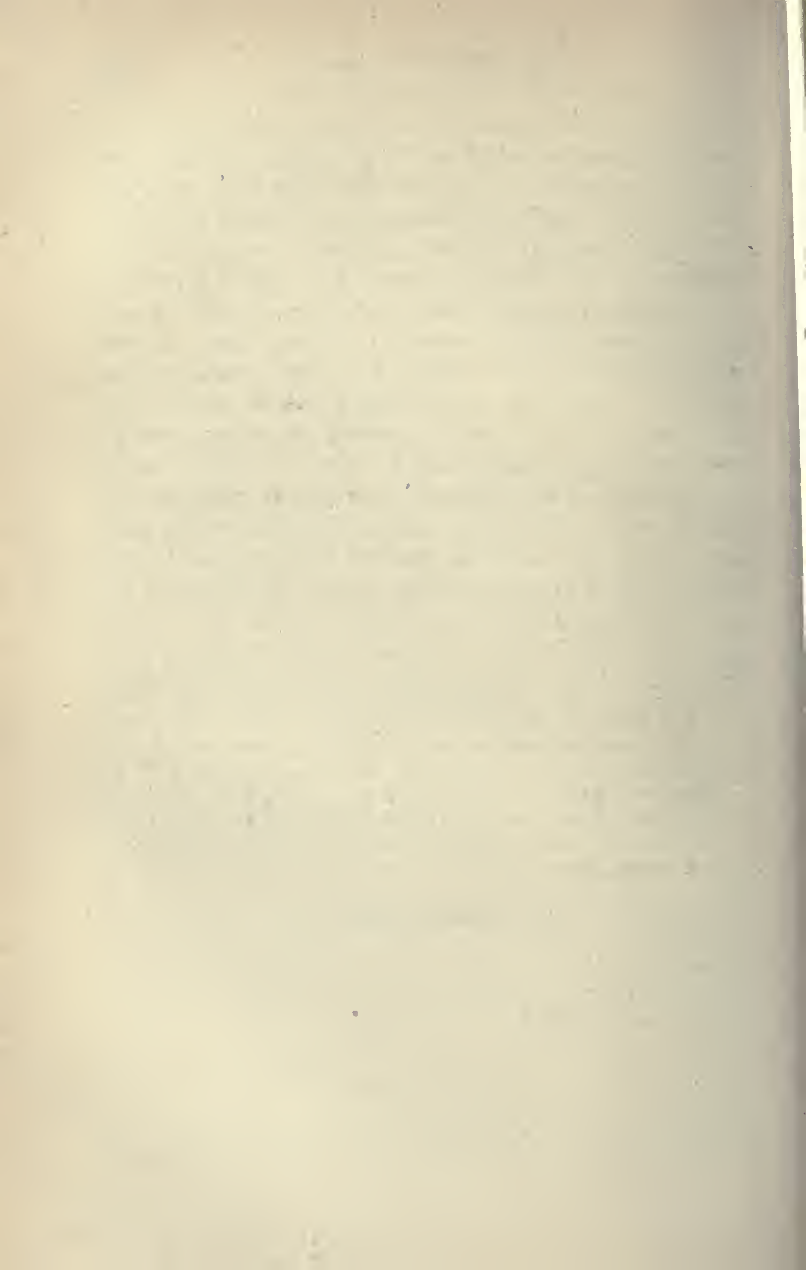
"Thus all this abundant wealth of money and of vivid life is Nature's investment in club mosses and the like so long ago. But what becomes of the coal which is burnt in yielding

the interest? Heat comes out of it, light comes out of it, and if we could gather together all that goes up the chimney, and all that remains in the grate of a thoroughly burnt coal fire, we should find ourselves in possession of a quantity of carbonic acid, water, ammonia, and mineral matters exactly equal in weight to the coal. But these are the very matters with which Nature supplied the club mosses which made coal. She is paid back principal and interest at the same time; and she straightway invests the carbonic acid, the water, and the ammonia in new forms of life, feeding with them the plants that now live. Thrifty Nature, surely! no prodigal, but the most notable of housekeepers." [1]

All this is true and well told; but who is "Nature," this goddess who, since the far-distant Carboniferous age, has been planning for man? Is this not another name for that Almighty Maker who foresaw and arranged all things for His people "before the foundation of the world."

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[1] *Contemporary Review*, 1871.



THE OLDEST AIR-BREATHERS.

DEDICATED TO THE MEMORY OF

MY FRIEND AND EARLY PATRON AND GUIDE

SIR CHARLES LYELL,

TO WHOM WE ARE INDEBTED FOR SO MUCH

OF THE SCIENTIFIC BASIS OF MODERN GEOLOGY.

Earliest Discoveries—Footprints of Batrachians—Labyrinthodents of the Carboniferous—Microsauria of the Carboniferous—Other Types—Discoveries in Erect Trees — Invertebrate Air-breathers, Land Snails, Millipedes, Insects, Spiders and Scorpions—General Conclusions





REMAINS OF HYLONOMUS LYELLI, DAWSON, 1859.

COAL MEASURES, SOUTH JOGGINS; NOVA SCOTIA.

Photograph of Type specimen somewhat enlarged, *Geol. Magazine*, 1891 (p. 279).
(1) Cranial bones and mandibles; (1*a*) Sternal and shoulder bones; (2) Mandible
(3) Humerus, ribs and vertebræ; (4) Hind limb; (5) Pelvis; (6) Caudal vertebræ.

CHAPTER X.

THE OLDEST AIR-BREATHERS.

ANIMAL life had its beginning in the waters, and to this day the waters are the chief habitat of animals, especially of the lower forms. If we divide the animal kingdom into great leading types, the lowest of these groups, the Protozoa, includes only aquatic forms; the next, that of the coral animals and their allies, is also aquatic. So are all the species of the Sea Urchins and Star Fishes. Of the remaining groups, the Mollusks, the Crustaceans, and the Worms are dominantly aquatic, only a small proportion being air-breathers. It is only in the two remaining groups, including the Insects and Spiders on the one hand, and the Vertebrate animals on the other, that we have terrestrial species in large proportion.

The same fact appears in geological time. The periods represented by the older Palæozoic rocks have been termed ages of invertebrates, and they might also be termed ages of aquatic animals. It is only gradually, and as it were with difficulty, that animals living in the less congenial element of air are introduced—at first a few scorpions and insects, later, land snails and amphibian reptiles, later still, the higher reptiles and the birds, and last of all the higher mammalia.

We need not wonder at this, for the conditions of life with reference to support, locomotion, and vicissitudes of temperature are more complex and difficult in air, and require more complicated and perfect machinery for their maintenance. Thus it was that probably half of the whole history of our

earth had passed away before the land became the abode of any large number and variety of animals; while it was only about the same time that the development of the vegetable kingdom became so complete as to afford food and shelter for air-breathers.

It is also worthy of note that it is only in comparatively recent times that we have been able to discover the oldest air-breathing animals, and geologists long believed that the time when animals had existed on the land was even shorter than it had actually been. This arose in part from the infrequency and rarity of preservation of the remains of the earliest creatures of this kind, and perhaps partly from the fact that collectors were not looking for them.

That there was dry land, even in the Cambro-Silurian period, we know, and can even trace its former shores. In Canada our old Laurentian coast extends for more than a thousand miles, from Labrador to Lake Superior, marking the southern border of the nucleus of the American continent in the Cambrian and Cambro-Silurian periods. Along a great part of this ancient coast we have the sand flats of the Potsdam Sandstone, affording very favourable conditions for the imbedding of land animals, did these exist; still, notwithstanding the zealous explorations of the Geological Survey, and of many amateurs, no trace of an air-breather has been found. I have myself followed the oldest Palæozoic beds up to their ancient limits in some localities, and collected the shells which the waves had dashed on the beach, and have seen under the Cambro-Silurian beds the old pre-Cambrian rocks pitted and indented with weather marks, showing that this shore was then gradually subsiding; yet the record of the rocks was totally silent as to the animals that may have trod the shore, or the trees that may have waved over it. All that can be said is that the sun shone, the rain fell, and the wind blew as it does now, and that the sea abounded in living creatures. The eyes

of Trilobites, the weathered Laurentian rocks, the wind ripples in the Potsdam sandstone, the rich fossils of the limestones, testify to these things. The existence of such conditions would lead us to hope that land animals may yet be found in these older formations. On the other hand, the gradual failure of one form of life after another, as we descend in the geological series, and the rarity of fishes and land plants in the Silurian rocks and their absence from the Cambrian, might induce us to believe that we have here reached the beginning of animal life, and have left far behind us those forms that inhabit the land.

Even in the Carboniferous period, though land plants abound, air-breathers are not numerous, and most of them have only been recently recognised. We know, however, with certainty that the dark and luxuriant forests of the coal period were not destitute of animal life. Reptiles[1] crept under their shade, land snails and millipedes fed on the rank leaves and decaying vegetable matter, and insects flitted through the air of the sunnier spots. Great interest attaches to these creatures; perhaps the first-born species in some of their respective types, and certainly belonging to one of the oldest land faunas, and presenting prototypes of future forms equally interesting to the geologist and the zoologist.

It has happened to the writer of these pages to have had some share in the finding of several of these ancient animals. The coal formation of Nova Scotia, so full in its development, so rich in fossil remains, and so well exposed in coast cliffs, has afforded admirable opportunities for such discoveries, which have been so far improved that at least twenty-five out of the not very large number of known Carboniferous land animals have been obtained from it.[2] The descriptions of

[1] I shall use the term reptile here in its broad, popular sense, as including Batrachians as well as reptiles proper.

[2] It appears that about a hundred species of Carboniferous reptiles

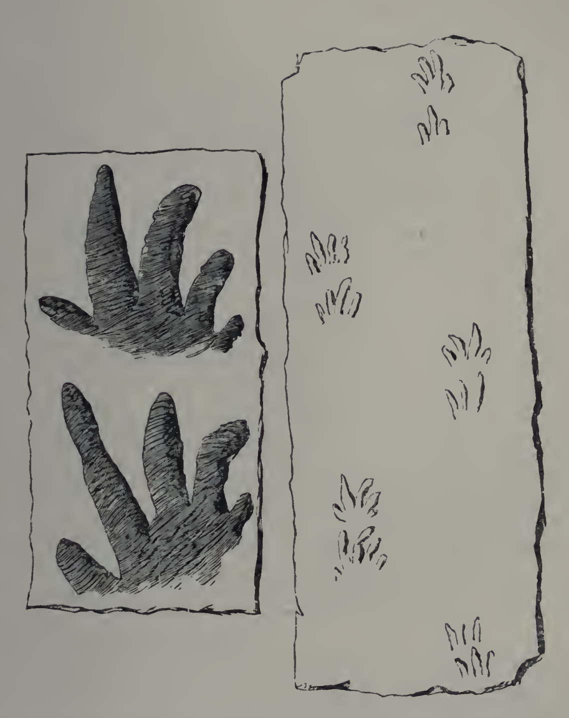
these creatures, found at various times and at various places, are scattered through papers ranging in date from 1844 to 1891,[1] and are too fragmentary to give complete information respecting the structures of the animals, and their conditions of existence.

Footprints.

It has often happened to geologists, as to other explorers of new regions, that footprints on the sand have guided them to the inhabitants of unknown lands, and such footprints, proverbially perishable, may be so preserved by being filled up with matter deposited in them as to endure for ever. This we may see to-day in the tracks of sandpipers and marks of rain-drops preserved in the layers of alluvial mud deposited by the tides of the Bay of Fundy, and which, if baked or hardened by pressure, might become imperishable, like the inscriptions of the old Chaldeans on their tablets of baked clay. The first trace ever observed of reptiles in the Carboniferous system consisted of a series of small but well-marked footprints found by Sir W. E. Logan, in 1841, in the lower coal measures of Horton Bluff, in Nova Scotia; and as the authors of most of our general works on geology have hitherto, in so far as I am aware, failed to do justice to this discovery, I shall notice it here in detail. In the year above mentioned, Sir William, then Mr. Logan, examined the coal fields of Pennsylvania and Nova Scotia, with the view of studying their structure, and extending the application of the discoveries as to beds with roots, or Stigmaria underclays, which he had made

have been recognised on the continent of Europe, in Great Britain, and in the United States. They belong to a number of distinct types, all, however, being of batrachian affinities.

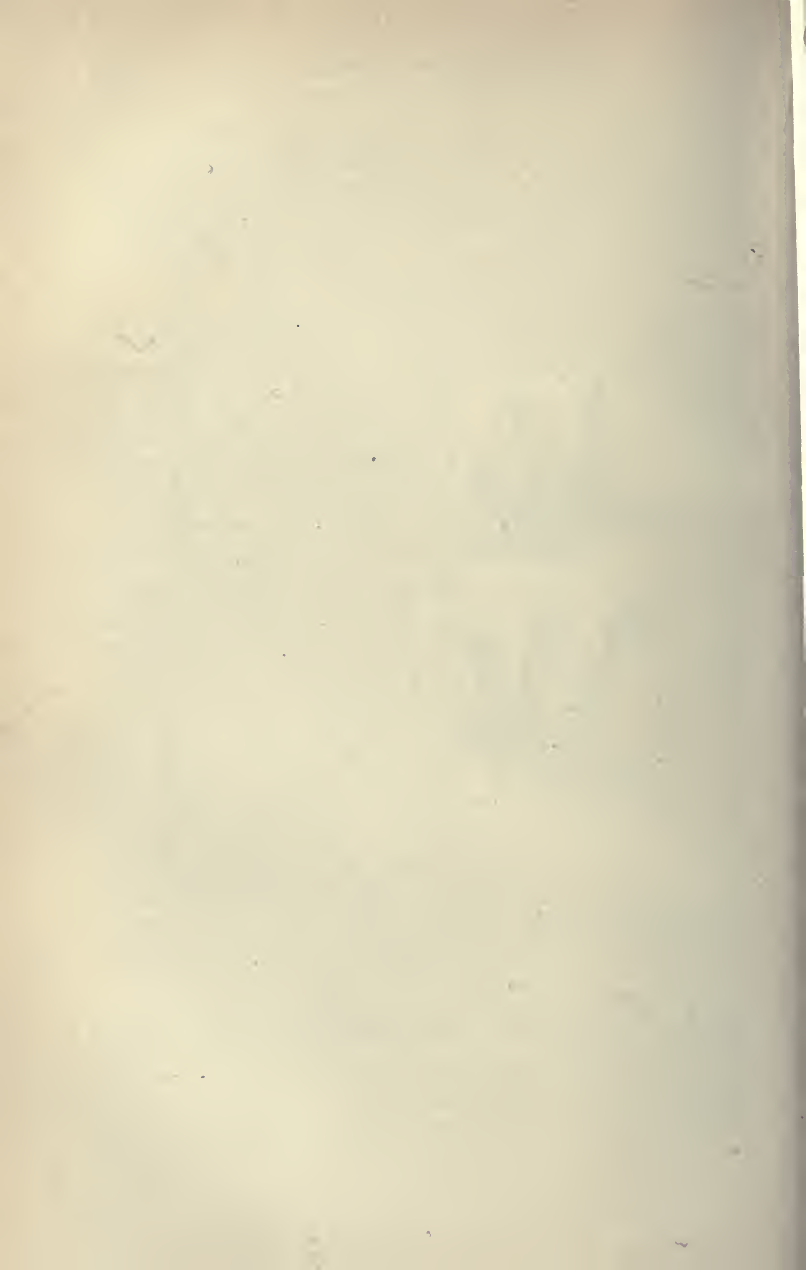
[1] Papers by Lyell, Owen, and the author, in the *Journal of the Geological Society of London*, i. ii. ix. x. xi. xvi. xvii. xviii.; "Acadian Geology," by the author; Papers in *Trans. Royal Society of London*, *Am. Jl. of Science*, and *Geological Magazine.*



Footprints of *Hylopus Logani*, Dawson, Lower Carboniferous, Nova Scotia.

Natural size and reduced.

These footprints were the first indications of Carboniferous land vertebrates ever observed; they were probably made by a Microsaurian and one of the earliest species of this type. They show a remarkable length of stride and development of limb.



in the Welsh coal fields. On his return to England he read a paper on these subjects before the Geological Society of London, in which he noticed the subject of reptilian footprints at Horton Bluff. The specimen was exhibited at the meeting of the Society, and was, I believe, admitted, on the high authority of Prof. Owen, to be probably reptilian. Unfortunately Sir William's paper appeared only in abstract in the Transactions; and in this abstract, though the footprints are mentioned, no opinion is expressed as to their nature. Sir William's own opinion is thus stated in a letter to me, dated June, 1843, when he was on his way to Canada, to commence the survey which has since developed so astonishing a mass of geological facts.

"Among the specimens which I carried from Horton Bluff, one is of very high interest. It exhibits the footprints of some reptilian animal. Owen has no doubt of the marks being genuine footprints. The rocks of Horton Bluff are below the gypsum of that neighbourhood; so that the specimen in question (if Lyell's views are correct[1]) comes from the very bottom of the coal series, or at any rate very low down in it, and demonstrates the existence of reptiles at an earlier epoch than has hitherto been determined; none having been previously found below the magnesian limestone, or, to give it Murchison's new name, the 'Permian era.'"

This extract is of interest, not merely as an item of evidence in relation to the matter now in hand, but as a mark in the progress of geological investigation. For the reasons above stated, the important discovery thus made in 1841, and published in 1842, was overlooked; and the discovery of reptilian bones by Von Dechen, at Saarbruck, in 1844, and that of footprints by Dr. King in the same year, in Pennsylvania,

[1] Sir Charles Lyell had then just read a paper announcing his discovery that the gypsiferous system of Nova Scotia is Lower Carboniferous, in which he mentions the footprints referred to, as being reptilian.

have been uniformly referred to as the first observations of this kind. Insects and Arachnidans, it may be observed, had previously been discovered in the coal formation in Europe.

The original specimen of these footprints is still in the collection of the Geological Survey of Canada, and a cast which Logan kindly presented to me is exhibited in the Peter Redpath Museum of McGill University. It is a slab of dark-coloured sandstone, glazed with fine clay on the surface; and having a series of seven footprints in two rows, distant about three inches; the distance of the impressions in each row being three or four inches, and the individual impressions about one inch in length. They seem to have been made by the points of the toes, which must have been armed with strong and apparently blunt claws, and appear as if either the surface had been somewhat firm, or the body of the animal had been partly water-borne. In one place only is there a distinct mark of the whole foot, as if the animal had exerted an unusual pressure in turning or stopping suddenly. One pair of feet—the fore feet, I presume—appear to have had four toes touching the ground; the other pair show only three or four, and it is to be observed that the outer toe, as in the larger footprints discovered by Dr. King, projects in the manner of a thumb, as in the cheirotherian tracks of the Trias. At a later date another series of footprints, possibly of the same animal, was obtained at the same place by Prof. Elder, and is now in the Peter Redpath Museum. Each foot in this shows five toes, and it is remarkable that the animal was digitigrade and took a long step for its size, indicating a somewhat high grade of quadrupedal organization. No mark of the tail or belly appears. The impressions are such as may have been made by animals similar to some of those to be described in the sequel.

Shortly afterward, Dr. Harding, of Windsor, when examining a cargo of sandstone which had been landed at that place from

Parrsboro', found on one of the slabs a very distinct series of footprints, each with four toes, and a trace of the fifth. Dr. Harding's specimen is now in the museum of King's College, Windsor. Its impressions are more distinct, but not very different otherwise from those above described, as found at Horton Bluff. The rocks at that place are probably of nearly the same age with those of Parrsboro'. I afterward examined the place from which this slab had been quarried, and satisfied myself that the beds are Carboniferous, and probably Lower Carboniferous. They were ripple-marked and sun-cracked, and I thought I could detect some footprints, though more obscure than those in Dr. Harding's slab. Similar footprints are also stated to have been found by Dr. Gesner, at Parrsboro'. All of these were from the lowest beds of the Carboniferous system.

I have since observed several instances of such impressions at the Joggins, at Horton, and near Windsor, showing that they are by no means rare, and that reptilian animals existed in no inconsiderable numbers throughout the coal field of Nova Scotia, and from the beginning to the end of the Carboniferous period. Most of these, when well preserved, show five toes both on the anterior and posterior limb. On comparing these earlier Carboniferous footprints with one another, it will be observed that they are of similar general character, and may have been made by one kind of animal, which must have had the fore and hind feet nearly of equal size, and a digitigrade mode of walking. Footprints of similar form are found in the coal formation, as well as others of much larger size. The latter are of two kinds. One of these shows short hind feet of digitigrade character and a long stride, in this resembling the smaller footprints of the Lower Carboniferous, which are remarkable for the length of limb which they indicate by the distance between the footprints. The other kind shows long hind feet, as if the whole heel were brought down to the

ground in a plantigrade manner. These have also the outer toe separated from the others, and sometimes provided with a long claw. The fore foot is sometimes smaller than the hind foot, and differently formed.[1] In these respects they resemble the great Labyrinthodont Batrachians of the subsequent Trias. Their stride also is comparatively short, and the rows of impressions wide apart, as if the body of the animal had been broad, and its limbs short.

We have thus two types of quadrupedal footprints, to the first of which I have given the name Hylopus, and have restricted the term Sauropus,[2] to the second. The first apparently belongs to the usually small reptiles of the group *Microsauria*, which had a well-marked lizard-like form, with well-developed limbs, and perhaps also to some of the smaller Labyrinthodonts, the second to the group of *Labyrinthodontia*, which were often of large size and with stout and short limbs and plantigrade hind feet. There are also some small and uncertain tracks, which may have been made by newt-like animals with short feet, and a singular trail of large size, and with a row of impressions at each side (Diplichnites),[3] which, if made by a vertebrate animal, would seem to indicate that serpentiform shape which we know belonged to some Carboniferous Batrachians.

The bones of these animals, however, hitherto found in Nova Scotia, may all have belonged to the two groups first named, the Labyrinthodontia and Microsauria, and I shall proceed to give some examples of each of these.

In leaving the footprints, I may merely mention that the animals which produced them may, in certain circumstances, have left distinct impressions only of three or four toes,

[1] Fine slabs of these footprints have been presented by Mr. Sandford Fleming to the Geological Survey of Canada.

[2] Given by King.

[3] Impressions and Footprints of Animals, *Am. Jour. Sci.*, 1873.

when they actually possessed five, while in other circumstances all may have left marks; and that, when wading in deep mud, their footprints were altogether different from those made on hard sand or clay. In some instances the impressions may have been made by animals wading or swimming in water, while in others the rain marks and sun cracks afford evidence that the surface was a subaërial one. They are chiefly interesting as indicating the wide diffusion and abundance of the creatures producing them, and that they haunted tidal flats and muddy shores, perhaps emerging from the water that they might bask in the sun, or possibly searching for food among the rejectamenta of the sea, or of lagunes and estuaries.

The Labyrinthodonts of the Coal Period, Baphetes Planiceps and Dendrerpeton Acadianum.

In the summer of 1851 I had occasion to spend a day at the Albion Mines in the eastern part of Nova Scotia, and on arriving at the railway station in the afternoon, found myself somewhat too early for the train. By way of improving the time thus left on my hands, I betook myself to the examination of a large pile of rubbish, consisting of shale and ironstone from one of the pits, and in which I had previously found scales and teeth of fishes. In the blocks of hard carbonaceous shale and earthy coal, of which the pile chiefly consisted, scales, teeth and coprolites often appeared on the weathered ends and surfaces as whitish spots. In looking for these, I observed one of much greater size than usual on the edge of a block, and on splitting it open, found a large flattened skull, about six inches broad, the cranial bones of which remained entire on one side of the mass, while the palate and teeth, in several fragments, came away with the other half. Carefully trimming the larger specimen, and gathering all the smaller fragments, I packed them up as safely as possible, and

returned from my little excursion much richer than I had hoped.

The specimen, on further examination, proved somewhat puzzling. I supposed it to be, most probably, the head of a large ganoid fish; but it seemed different from anything of this kind with which I could compare it; and at a distance from comparative anatomists, and without sufficient means of determination, I dared not refer it to anything higher in the animal scale. Hoping for further light, I packed it up with some other specimens, and sent it to the Secretary of the Geological Society of London, with an explanatory note as to its geological position, and requesting that it might be submitted to some one versed in such fossils. For a year or two, however, it remained as quietly in the Society's collection as if in its original bed in the coal mine, until attention having been attracted to such remains by the discoveries made by Sir Charles Lyell and myself in 1852, at the South Joggins, and published in 1853,[1] the Secretary or President of the Society re-discovered the specimen, and handed it to Sir Richard Owen, by whom it was described in December, 1853,[2] under the name of *Baphetes planiceps*, which may be interpreted the "flat-headed diving animal," in allusion to the flatness of the creature's skull, and the possibility that it may have been in the habit of diving.

The parts preserved in my specimen are the bones of the anterior and upper part of the skull in one fragment, and the teeth and palatal bones in others. These parts were carefully examined and described by Owen, and the details will be found in his papers referred to in the note. We may merely observe here that the form and arrangement of the bones showed batrachian affinities, that the surface of the cranium was sculptured in the manner of the group of

[1] *Journal of Geological Society of London*, vol. ix.

[2] *Journal of Geological Society*, vol. x.; and additional notes, vol. xi.

Labyrinthodonts, and that the teeth possessed the peculiar and complicated plication of the ivory and enamel seen in creatures of this type. The whole of these characters are regarded as allying the animal with the great crocodilian frogs of the Trias of Europe, first known as *Cheirotherians*, owing to the remarkable hand-like impressions of their feet, and afterwards as *Labyrinthodonts*, from the beautifully complicated convolutions of the ivory of their teeth.

Unfortunately the original specimen exhibited only the head, and after much and frequent subsequent searching, the only other bones found are a scapula, or shoulder bone, and one of the surface scales which served for protection, and which indicate at least that the creature possessed walking limbs and was armed with bony scales sculptured in the same manner with the skull bones.

Of the general form and dimensions of *Baphetes*, the facts at present known do not enable us to say much. Its formidable teeth and strong maxillary bones show that it must have devoured animals of considerable size, probably the fishes whose remains are found with it, or the smaller reptiles of the coal. It must, in short, have been crocodilian, rather than frog-like, in its mode of life; but whether, like the Labyrinthodonts, it had strong limbs and a short body, or like the crocodiles, an elongated form and a powerful natatory tail, the remains do not decide. One of the limbs or a vertebra of the tail would settle this question, but neither has as yet been found. That there were large animals of the labyrinthodontal form in the coal period is proved by the footprints discovered by Dr. King in Pennsylvania, which may have been produced by an animal of the type of *Baphetes*, as well as by those of *Sauropus unguifer* from the Carboniferous of Nova Scotia, and which would very well suit an animal of this size and probable form. On the other hand, that there were large swimming reptiles seems established

by the discovery of the vertebræ of *Eosaurus Acadianus*, at the Joggins, by Marsh.[1] The locomotion of *Baphetes* must have been vigorous and rapid, but it may have been effected both on land and in water, and either by feet or tail, or both. A jawbone found at the Joggins in Nova Scotia, and to which I have attached the name *Baphetes minor*, may have belonged to a second species. Great Batrachians allied to Baphetes, but different specifically or generically, have since been found in the coal formations of Great Britain, the continent of Europe and the United States.

With the nature of the habitat of this formidable creature we are better acquainted. The area of the Albion Mines coal field was somewhat exceptional in its character. It seems to have been a bay or indentation in the Silurian land, separated from the remainder of the coal field by a high shingle beach, now a bed of conglomerate. Owing to this circumstance, while in the other portions of the Nova Scotia coal field the beds of coal are thin, and alternate with sandstones and shales, at the Albion Mines a vast thickness of almost unmixed vegetable matter has been deposited, constituting the "main seam' of thirty-eight feet thick, and the "deep seam," twenty-four feet thick, as well as still thicker beds of highly carbonaceous shale. But, though the area of the Albion coal measures was thus separated, and preserved from marine incursions, it must have been often submerged, and probably had connection with the sea, through rivers or channels cutting the enclosing beach. Hence beds of earthy matter occur in it, containing remains of large fishes. One of the most important of these is that known as the "Holing stone," a band of black highly carbonaceous shale, coaly matter, and clay ironstone, occurring in the main seam, about five feet below its roof, and varying in thickness from two inches to nearly two feet. It was from this band that the rubbish heap in which I found the

[1] *Silliman's Journal*, 1859.

skull of *Baphetes planiceps* was derived. It is a laminated bed, sometimes hard and containing much ironstone, in other places soft and shaly, but always black and carbonaceous, and often with layers of coarse coal, though with few fossil plants retaining their forms. It contains large round flat scales and flattened curved teeth, which I attribute to a fish of the genus *Rhizodus*, resembling, if not identical with, *R. lancifer*, Newberry. With these are double-pointed shark-like teeth, and long cylindrical spines of a species of *Diplodus*, which I have named *D. acinaces*.[1] There are also shells of the minute *Spirorbis*, so common in the coal measures of other parts of Nova Scotia, and abundance of fragments of coprolitic matter, or fossil excrement, sometimes containing bones and scales of fishes.

It is evident that the "Holing stone" indicates one of those periods in which the Albion coal area, or a large part of it, was under water, probably fresh or brackish, as there are no properly marine shells in this, or any of the other beds of this coal series. We may then imagine a large lake or lagune, loaded with trunks of trees and decaying vegetable matter, having in its shallow parts, and along its sides, dense brakes of *Calamites*, and forests of *Sigillaria*, *Lepidodendron*, and other trees of the period, extending far on every side as damp pestilential swamps. In such a habitat, uninviting to us, but no doubt suited to *Baphetes*, that creature crawled through swamps and thickets, wallowed in flats of black mud, or swam and dived in search of its finny prey. It was, in so far as we know, the monarch of these swamps, though there is, as already stated, evidence of the existence of similar creatures of this type quite as large in other parts of the Nova Scotia coal field. We must now notice a smaller animal belonging to the same family of Labyrinthodonts.

[1] "Supplement to Acadian Geology," pp. 43 and 50. These fishes are now known under the generic name Leptacanthus.

The geology of Nova Scotia is largely indebted to the world-embracing labours of Sir Charles Lyell. Though much had previously been done by others, his personal explorations in 1842, and his paper on the gypsiferous formation, published in the following year, first gave form and shape to some of the more difficult features of the geology of the country, and brought it into relation with that of other parts of the world. In geological investigation, as in many other things, patient plodding may accumulate large stores of fact, but the magic wand of genius is required to bring out the true value and significance of these stores of knowledge. It is scarcely too much to say that the exploration of a few weeks, and subsequent study of the subject by Sir Charles, with the impulse and guidance given to the labours of others, did as much for Nova Scotia as might have been effected by years of laborious work under less competent heads.

Sir Charles naturally continued to take an interest in the geology of Nova Scotia, and to entertain a desire to explore more fully some of those magnificent coast sections which he had but hastily examined; and when, in 1851, he had occasion to revisit the United States, he made an appointment with the writer of these pages to spend a few days in renewed explorations of the cliffs of the South Joggins. The object specially in view was the thorough examination of the beds of the true coal measures, with reference to their contained fossils, and the conditions of accumulation of the coal; and the results were given to the world in a joint paper on "The remains of a reptile and a land shell discovered in the interior of an erect tree in the coal measures of Nova Scotia," and in the writer's paper on the "Coal Measures of the South Joggins";[1] while other important investigations grew out of the following up of these researches, and much matter in

[1] *Journal of the Geological Society of London*, vols. ix. and x.; and "Acadian Geology."

relation to the vegetable fossils still remains to be worked up. It is with the more striking fact of the discovery of the remains of a reptile in the coal measures that we have now to do.

The South Joggins Section is, among other things, remarkable for the number of beds which contain remains of erect trees imbedded *in situ*: these trees are for the most part Sigillariæ, those great-ribbed pillar-like trees which seem to have been so characteristic of the forests of the coal formation flats and swamps, and so important contributors to the formation of coal. They vary in diameter from six inches to five feet. They have grown on underclays and wet soils, similar to those on which the coal was accumulated; and these having been submerged or buried by mud carried down by inundations, the trees, killed by the accumulations around their stems, have decayed, and their tops being broken off at the level of the mud or sand, the cylindrical cavities left open by the disappearance of the wood, and preserved in their form by the greater durability of the bark, have been filled with sand and clay. This, now hardened into stone, constitutes pillar-like casts of the trees, which may often be seen exposed in the cliffs, and which, as these waste away, fall upon the beach. The sandstones enveloping these pillared trunks of the ancient Sigillariæ of the coal, are laminated or bedded, and the laminæ, when exposed, split apart with the weather, so that the trees themselves become broken across; this being often aided by the arrangement of the matter within the trunks, in layers more or less corresponding to those without. Thus one of these fossil trees usually falls to the beach in a series of discs, somewhat resembling the grindstones which are extensively manufactured on the coast. The surfaces of these fragments often exhibit remains of plants which have been washed into the hollow trunks, and have been imbedded there; and in our explorations of the shore, we always carefully scrutinized such specimens, both with the view of observ-

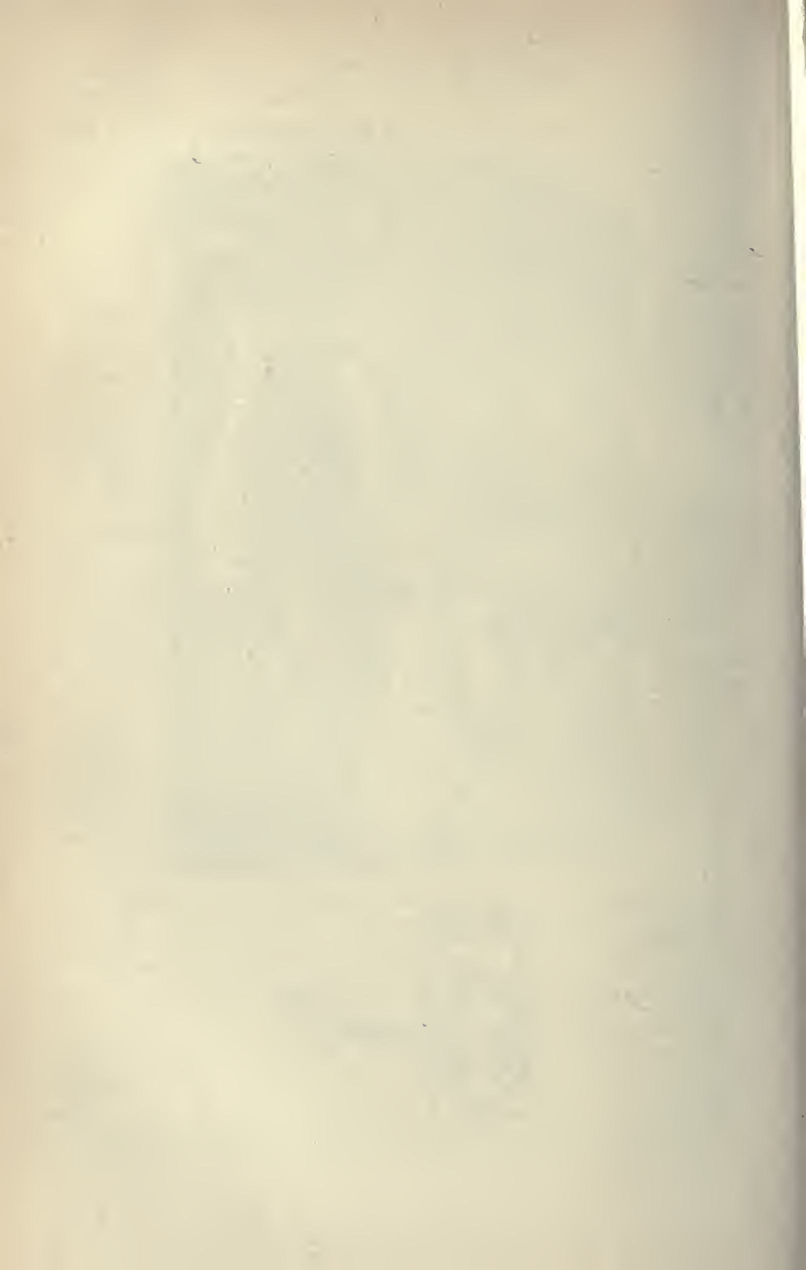
ing whether they retained the superficial markings of Sigillariæ, and with reference to the fossils contained in them. It was while examining a pile of these "fossil grindstones" that we were surprised by finding on one of them what seemed to be fragments of bone. On careful search other bones appeared, and they had the aspect, not of remains of fishes, of which many species are found fossil in these coal measures, but rather of limb bones of a quadruped. The fallen pieces of the tree were carefully broken up, and other bones disengaged, and at length a jaw with teeth made its appearance. We felt quite confident, from the first, that these bones were reptilian; and the whole, being carefully packed and labelled, were taken by Sir Charles to the United States, and submitted to Prof. J. Wyman of Cambridge; who recognised their reptilian character, and prepared descriptive notes of the principal bones, which appeared to have belonged to two species. He also observed among the fragments an object of different character, apparently a shell; which was recognised by Dr. Gould of Boston, and afterward by M. Deshayes, as probably a land-snail, and has since been named *Pupa vetusta*.

The specimens were subsequently taken to London and re-examined by Prof. Owen, who confirmed Wyman's inferences, added other characters to the description, and named the larger and better preserved species *Dendrerpeton Acadianum*, in allusion to its discovery in the interior of a tree, and to its native country of Acadia or Nova Scotia. It is necessary to state in explanation of the fragmentary character of the remains obtained, that in the decay of the animals imbedded in the erect trees at the Joggins, their skeletons have become disarticulated, and the portions scattered, either by falling into the interstices of the vegetable fragments in the bottom of the hollow trunks, or by the water with which these may have sometimes been partly filled. We thus usually obtain only separate bones; and though all of these are no doubt present



HUMERUS AND MANDIBLES OF DENDRERPETON ACADIANUM. Natural size, with one of the teeth enlarged. (From a Photograph.)

The specimen illustrates the sculptured bones of Dendrerpeton and its plaited teeth, as well as large size and massive development of the arm bone.



in each case, it is often impossible in breaking up the hard matrix to recover more than a portion of them. The original description by Owen was therefore based on somewhat imperfect material, but additional specimens subsequently found have supplemented it in such a manner as to enable us somewhat completely to restore in imagination the form of the animal, which, though much smaller than *Baphetes*, agrees with it in its sculptured bones, in its bony armature, especially beneath, and in its plicated teeth.

In form, *Dendrerpeton Acadianum* was probably lizard-like; with a broad flat head, short stout limbs and an elongated tail; and having its skin, and more particularly that of the belly, protected by small bony plates closely overlapping each other, and arranged *en chevron*, in oblique rows meeting on the mesial line, where in front was a thoracic plate. It may have attained the length of two feet. The form of the head is not unlike that of *Baphetes*, but longer in proportion; and much resembles that of the labyrinthodont reptiles of the Trias. The bones of the skull are sculptured as in *Baphetes*, but in a smaller pattern.

The fore limb of the adult animal, including the toes, must have been four or five inches in length, and is of massive proportions. The bones were hollow, and in the case of the phalanges the bony walls were thin, so that they are often crushed flat. The humerus, or arm bone, however, was a strong bone, with thick walls and a cancellated structure toward its extremities; still even these have sometimes yielded to the great pressure to which they have been subjected. The cavity of the interior of the limb bones is usually filled with calcspar stained with organic matter, but showing no structure; and the inner side of the bony wall is smooth without any indication of cartilaginous matter lining it.

The vertebræ, in the external aspect of their bodies, remind one of those of fishes, expanding toward the extremities, and

being deeply hollowed by conical cavities, which appear even to meet in the centre. There is, however, a large and flattened neural spine. The vertebræ are usually much crushed, and it is almost impossible to disengage them from the stone. The ribs are long and curved, showing a reptilian style of chest. The posterior limb seems to have been not larger than the anterior, perhaps smaller. The tibia, or principal bone of the fore leg is much flattened at the extremity, as in some Labyrinthodonts, and the foot must have been broad, and probably suited for swimming, or walking on soft mud, or both. That the hind limb was adapted for walking is shown, not merely by the form of the bones, but also by that of the pelvis.

The external scales are thin, oblique-rhomboidal or elongated-oval, marked with slight concentric lines, but otherwise smooth, and having a thickened ridge or margin, in which they resemble those of *Archegosaurus*, and also those of *Pholidogaster pisciformis*, described by Huxley from the Edinburgh coal field,—an animal which indeed apppears in most respects to have a close affinity with *Dendrerpeton*. The microscopic structure of the scales is quite similar to that of the other bones, and different from that of the scales of ganoid fishes, the shape of the cells being batrachian. For other particulars of its structure reference may be made to the papers named at the end of the chapter.

With respect to the affinities of the creature, I think it is obvious that it is most nearly related to the group of Labyrinthodonts, and that it has the same singular mixture of batrachian and reptilian characters which distinguish these ancient animals, and which give them the appearance of prototypes of the reptilian class. A second and smaller species of Dendrerpeton was subsequently obtained at the Joggins, and others have been found, more especially by Fritsch, in the Carboniferous and Permian of Europe.

This ancient inhabitant of the coal swamps of Nova Scotia

was, in short, as we often find to be the case with the earliest forms of life, the possessor of powers and structures not usually, in the modern world, combined in a single species. It was certainly not a fish, yet its bony scales and the form of its vertebræ, and of its teeth, might, in the absence of other evidence, cause it to be mistaken for one. We call it a Batrachian, yet its dentition, the sculpturing of the bones of its skull, which were certainly no more external plates than the similar bones of a crocodile, its ribs, and the structure of its limbs, remind us of the higher reptiles; and we do not know that it ever possessed gills, or passed through a larval or fish-like condition. Still, in a great many important characters, its structures are undoubtedly batrachian. It stands, in short, in the same position with the *Lepidodendra* and *Sigillariæ* under whose shade it crept, which, though placed by palæobotanists in alliance with certain modern groups of plants, manifestly differed from these in many of their characters, and occupied a different position in nature. In the coal period the distinctions of physical and vital conditions were not well defined. Dry land and water, terrestrial and aquatic plants and animals, and lower and higher forms of animal and vegetable life, are consequently not easily separated from each other. This is no doubt a state of things characteristic of the earlier stages of the earth's history, yet not necessarily so; for there are some reasons, derived from fossil plants, for believing that in the preceding Devonian period there was less of this, and consequently that there may then have been a higher and more varied animal life than in the coal period.[1]

The dentition of *Dendrerpeton* shows it to have been carnivorous in a high degree. It may have captured fishes and smaller reptiles, either on land or in water, and very probably fed on dead carcases as well. If, as seems likely, any of the

[1] See the author's paper on Devonian plants, *Journal of the Geological Society*, vol. xviii. p. 328.

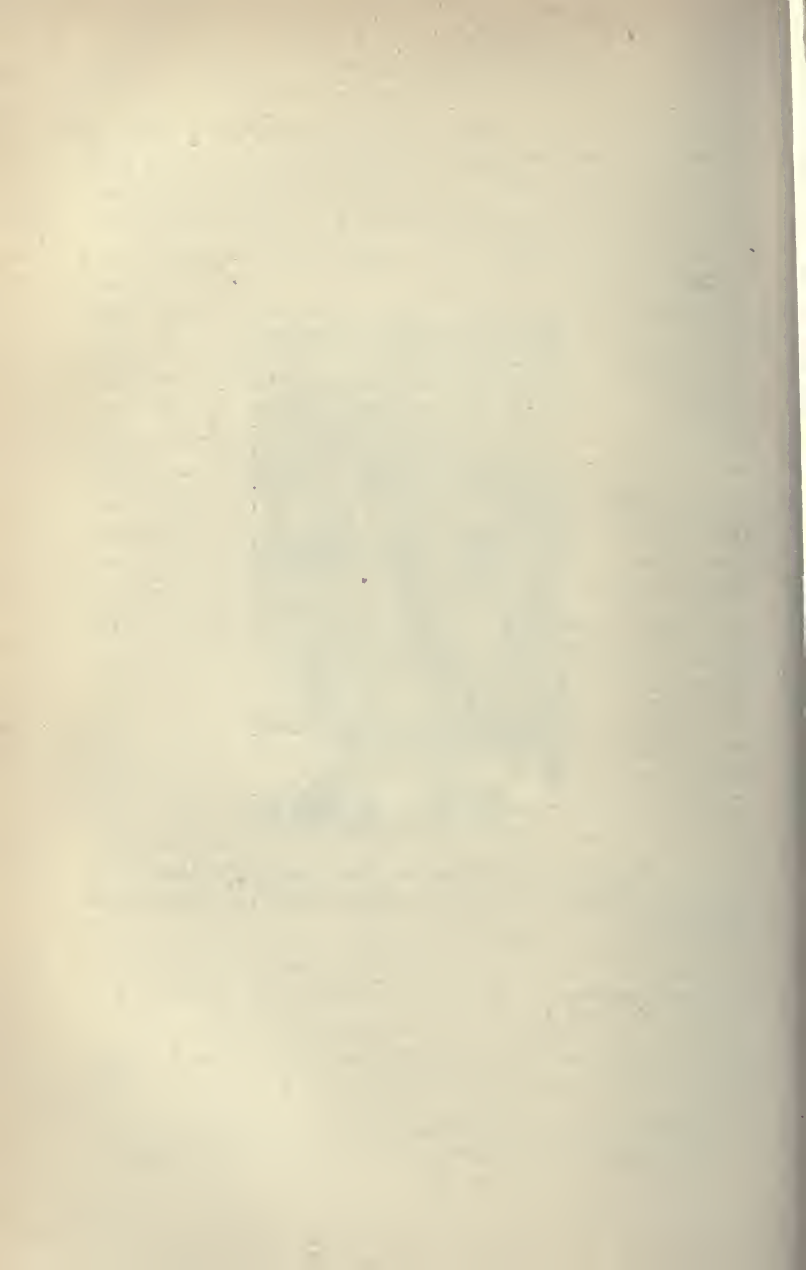
footprints referred to previously belong to this animal, it must have frequented the shores, either in search of garbage, or on its way to and from the waters. The occurrence of its remains in the stumps of Sigillaria, with land snails and millipedes, shows also that it crept in the shade of the woods in search of food; and in noticing coprolitic matter, in a subsequent page, I shall show that remains of excrementitious substances, probably of this species, contain fragments attributable to smaller reptiles, and other animals of the land.

All the bones of *Dendrerpeton* hitherto found, as well as those of the smaller reptilian species hereafter described, have been obtained from the interior of erect Sigillariæ, and all of these in one of the many beds, which, at the Joggins, contain such remains. The thick cellular inner bark of Sigillaria was very perishable; the slender woody axis was somewhat more durable; but near the surface of the stem, in large trunks, there was a layer of elongated cells, or bast tissue, of considerable durability, and the outer bark was exceedingly dense and indestructible.[1] Hence an erect tree, partly imbedded in sediment, and subjected to the influence of the weather, became a hollow shell of bark; in the bottom of which lay the decaying remains of the woody axis, and shreds of the fibrous bark. In ordinary circumstances such hollow stems would be almost immediately filled with silt and sand, deposited in the numerous inundations and subsidences of the coal swamps. Where, however, they remained open for a considerable time, they would constitute a series of pitfalls, into which animals walking on the surface might be precipitated; and being probably often partly covered by remains of prostrate trunks, or by vegetation growing around their mouths, they would be places of retreat and abode for land snails and such creatures. When the surface was again inundated or submerged, all such

[1] See a paper by the author, on the Structures of Coal, *Journal of the Geological Society*, vol. xv.; also "Supplement to Acadian Geology."



A REPTILIFEROUS TREE *in situ*, South Joggins, N. Scotia.
This is a sketch of a tree which afforded remains of Dendrerpeton, Pupæ, etc.



animals, with the remains of those which had fallen into the deeper pits, would be imbedded in the sediment which would then fill up the holes. These seem to have been the precise conditions of the bed which has afforded all these remains.

The history of a bed containing reptiliferous erect trees would thus be somewhat as follows :—

A forest or grove of the large-ribbed trees known as *Sigillariæ*, was either submerged by subsidence, or, growing on low ground, was invaded with the muddy waters of an inundation, or successive inundations, so that the trunks were buried to the depth of several feet. The projecting tops having been removed by subaërial decay, the buried stumps became hollow, while their hard outer bark remained intact. They thus became hollow cylinders in a vertical position, and open at top. The surface having then become dry land, covered with vegetation, was haunted by small quadrupeds and other land animals, which from time to time fell into the open holes, in some cases nine feet deep, and could not extricate themselves. On their death, and the decomposition of their soft parts, their bones and other hard portions remained in the bottom of the tree intermixed with any vegetable *débris* or soil washed in by rain, and which formed thin layers separating successive animal deposits from each other. Finally, the area was again submerged or overflowed by water, bearing sand and mud. The hollow trees were filled to the top, and their animal contents thus sealed up. At length the material filling the trees was by pressure and the access of cementing matter hardened into stone, not infrequently harder than that of the containing beds, and the whole being tilted to an angle of 20°, and elevated into land exposed to the action of the tides and waves, these singular coffins present themselves as stony cylinders projecting from the cliff or reef, and can be extracted and their contents studied.

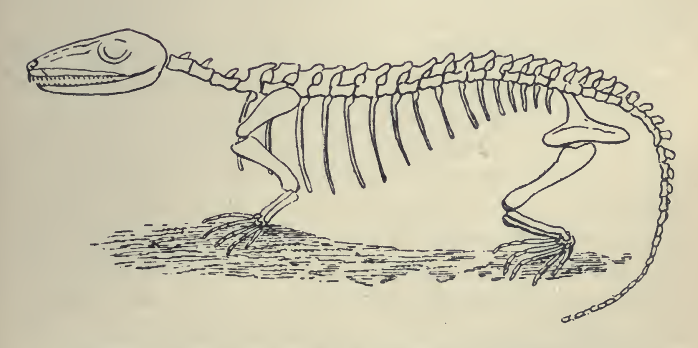
The singular combination of accidents above detailed was,

of course, of very rare occurrence, and in point of fact we know only one set of beds at the South Joggins in which such remains so preserved occur; nor is there, so far as I am aware, any other known instance elsewhere. Even in the beds in question only a portion of the trees, about fifteen in thirty, have afforded animal remains. We have, however, thus been enabled to obtain specimens of a number of species which would probably otherwise have been unknown, being less likely than others to be preserved in properly aqueous deposits. Such discoveries, on the one hand impress us with the imperfection of the geological record; on the other, they show us the singular provisions which have been made in the course of geological time for preserving the relics of the ancient world, and which await the industry and skill of collectors to disclose their hidden treasures.

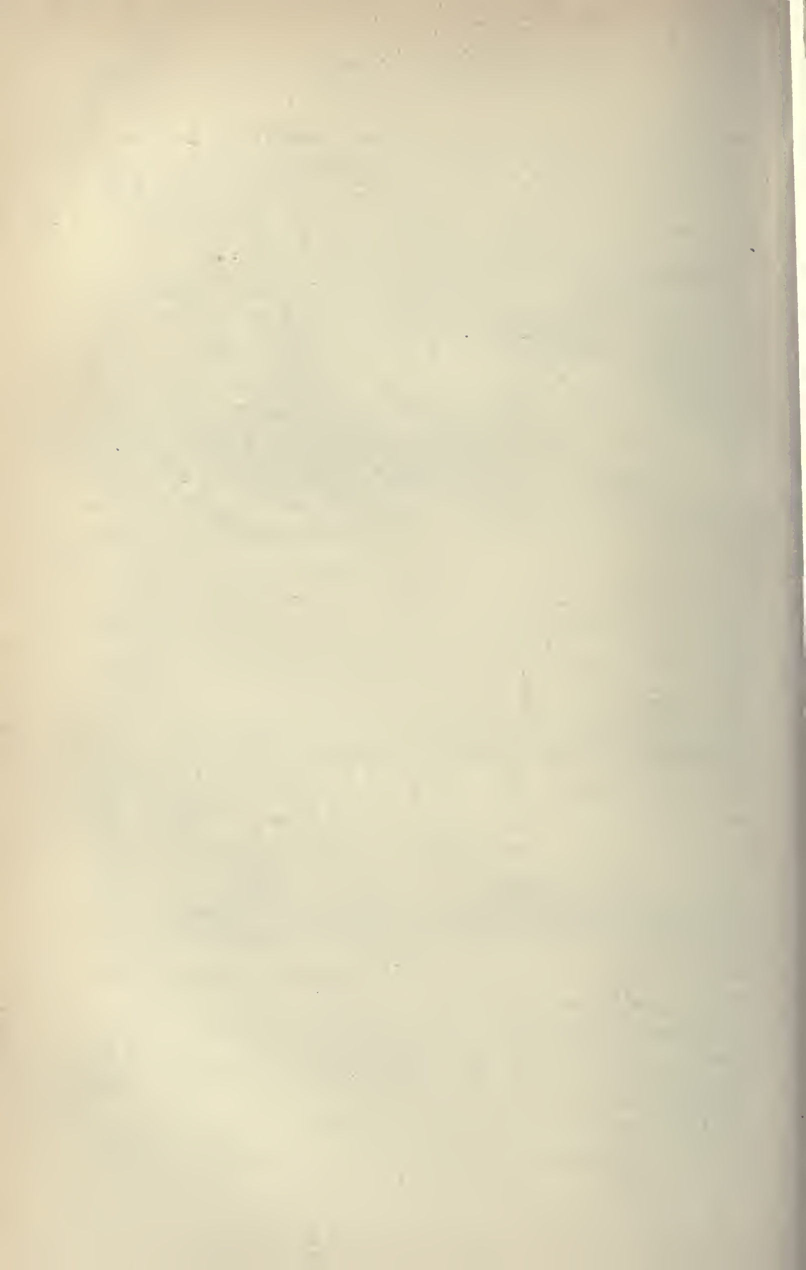
I may add that I believe all the trees, about thirty in number, which have become exposed in this bed since its discovery, have been ransacked for such remains; and that while the majority have afforded some reward for the labour, some have been far more rich than others in their contents. It is also to be observed that owing to the mode of accumulation of the mass filling the trees, the bones are usually found scattered in every position, and those of different species intermingled; and that being often much more friable than the matrix, much labour is required for their development; while after all has been done, the result is a congeries of fragments. A few specimens only have been found, showing skeletons complete, or nearly so, and I shall endeavour to figure one or two of these by way of illustration in the present chapter.

The beds on a level with the top of the reptiliferous erect trees are arenaceous sandstones, with numerous erect *Calamites*. I have searched the surfaces of these beds in vain for bones or footprints of the reptiles which must have traversed them, and which, but for hollow erect trees, would apparently





A TYPICAL CARBONIFEROUS MICROSAURIAN, *Hylonomus Lyelli*—Restoration showing dermal armour and ornaments. Skeleton restored from measurements of the bones of the type specimen figured at the beginning of the chapter.



have left no trace of their existence. On a surface of similar character, sixty feet higher, and separated by three coals, with their accompaniments, and a very thick compact sandstone, I observed a series of footprints, which may be those of *Dendrerpeton* or *Hylonomus.*

SPECIES OF MICROSAURIA. HYLONOMUS LYELLI.

In the original reptiliferous tree discovered by Sir C. Lyell and the writer, at the Joggins, in 1851, there were, beside the bones of *Dendrerpeton Acadianum*, some small elongated vertebræ, evidently of a different species. These were first detected by Prof. Wyman, in his examination of these specimens, and were figured, but not named, in the original notice of the specimens. In a subsequent visit to the Joggins I obtained from another erect stump many additional remains of these smaller reptiles, and, on careful comparison of the specimens, was induced to refer them to three species, all apparently generically allied. I proposed for them the generic name *Hylonomus*, "forest dweller." They were described in the Proceedings of the Geological Society for 1859, with illustrations of the teeth and other characteristic parts.[1] The smaller species first described I named *H. Wymani*; the next in size, that to which this article refers, and which was represented by a larger number of specimens, I adopted as a type of the genus, and dedicated to Sir Charles Lyell. The third and largest, represented only by a few fragments of a single skeleton, was named *H. aciedentatus.* This I had subsequently to remove to a new genus, *Smilerpeton.*

Hylonomus Lyelli was an animal of small size. Its skull is about an inch in length, and its whole body, including the tail, could not have been more than six or seven inches long. The bones appear to have been thin and easily separable ; and even

[1] *Journal of Geological Society*, vol. xvi.

when they remain together, are so much crushed as to render the shape of the skull not easily discernible. They are smooth on the outer surface to the naked eye ; and under a lens show only delicate, uneven striæ and minute dots. They are more dense and hard than those of *Dendrerpeton*, and the bone cells are more elongated in form. The bones of the snout would seem to have been somewhat elongated and narrow. A specimen in my possession shows the parietal and occipital bones, or the greater part of them, united and retaining their form. We learn from them that the brain case was rounded, and that there was a parietal foramen. There would seem also to have been two occipital condyles, as in modern Batrachians. Several well-preserved specimens of the maxillary and mandibular bones have been obtained. They are smooth, or nearly so, like those of the skull, and are furnished with numerous sharp, conical teeth, anchylosed to the jaw, in a partial groove formed by the outer ridge of the bone. In the anterior part of the lower jaw there is a group of teeth larger than the others. The total number of teeth in each ramus of the lower jaw was about forty, and the number in each maxillary bone about thirty. The teeth are perfectly simple, hollow within, and with very fine radiating tubes of ivory. The vertebræ have the bodies cyclindrical or hour-glass shaped, covered with a thin, hard, bony plate, and having within a cavity of the form of two cones, attached by the apices. This cavity was completely surrounded by bone, as it is filled with stained calcspar in the same manner as the cavities of the limb bones. It was probably occupied by cartilage. The vertebræ were apparently bi-concave, and are furnished with upper and lateral processes similar to those of small lacertian animals. The ribs are long, curved, and at the proximal end have a shoulder and neck. They are hollow, with thin hard bony walls. The anterior limb, judging from the fragment procured, seems to have been slender, with long toes, four or ssibly five in number. The

posterior limb was longer and stronger, and attached to a pelvis so large and broad as to give the impression that the creature enlarged considerably in size toward the posterior extremity of the body, and that it may have been in the habit of sitting erect. The thigh bone is large and well formed, with a distinct head and trochanter, and the lower extremity flattened and moulded into two articulating surfaces for the tibia and fibula, the fragments of which show that they were much shorter. The toes of the hind feet have been seen only in detached joints. They seem to have been thicker than those of the fore foot. Detached vertebræ, which seem to be caudal, have been found, and show that the tail was long and probably not flattened. The limb bones are usually somewhat crushed and flattened, especially at their articular extremities, and this seems to have led to the error of supposing that this flattened form was their normal condition ; there can be no doubt, however, that it is merely an effect of pressure. The limb bones present in cross section a wall of dense bone with elongated bone-cells, surrounding a cavity now filled with brown calcspar, and originally occupied with cartilage or marrow. I desire to specify the above points because I believe that most of the creatures referred by Fritsch, Credner, and other European naturalists to the Microsauria are of inferior grade to Hylonomus, though admitted to present points of approximation to the true reptiles. Woodward has recently described the remains of a Microsaurian from the English coal formation. Nothing is more remarkable in the skeleton of this creature than the contrast between the perfect and beautiful forms of its bones, and their imperfectly ossified condition, a circumstance which raises the question whether these specimens may not represent the young of some reptile of larger size.

The dermal covering of this animal is represented in part by oval bony scales, which are so constantly associated with its bones that I can have no doubt that they belonged to it, being,

perhaps, the clothing of its lower or abdominal parts. But the most remarkable and unexpected feature of this little creature was the beautiful and ornate scaly covering of its back and sides. Modern Batrachians are characteristically naked, and though we know that some fossil species had coverings below of bony scales, these seemed rather to ally them with bony fishes. One of the specimens of Hylonomus had associated with it a quantity of crumpled shining skin, black and carbonaceous, and which may perhaps have been tanned and so preserved by the water filling the hollow tree impregnated with solution of tannin from the bark. This skin was covered with minute overlapping scales, which, under the microscope, showed the structure of horn rather than of bone. Besides these ordinary scales there were bony prominences, like those of the horned frog, on the back and shoulders, and a species of epaulettes made of long horny bristles curved downward, and apparently placed at the edges of the shoulders. Besides these there were in front and at the side rows of pendants or lappets, all no doubt ornamented with colouring, though now perfectly black. It may be asked what was the use of the ornate covering, and perhaps the question raises that perplexing problem, of the use of beauty in a world where there were no animals with higher æsthetic faculties than those of Batrachians. Scudder suggests a somewhat prosaic use in supposing them to be an armour against the venomous scorpions which were the contemporaries of these little reptiles, and some of them almost as large in size. But the word "venomous" raises another question, for we only infer that the scorpions were venomous from modern analogy and traces of an inflated joint at the end of the tail in some specimens. We have no absolute certainty that the subtle and complex organic poison of the scorpion, and his beautiful injection syringe for placing it under the skin, were perfected at this early time. Thus we have in the far back Carboniferous age a creature as

elaborately ornamented and protected as any of the modern lizards, and this, let it be observed, constitutes another and important departure from that batrachian type to which these animals are supposed to conform. I may add here that subsequently portions of skin were found, which from their size probably belonged to *Dendrerpeton*, and that these also were scaly and had lappets, though they did not appear to have the horny tubercles and fringes. It may be asked why such advanced characters should be found in Nova Scotia alone. The answer is that the circumstances of preservation in the erect trees were peculiar, and that only animals of purely terrestrial habits could find access to them, whereas the remains of reptiles found in the Carboniferous elsewhere are in aqueous beds in which aquatic forms were more likely to be preserved, and in which all the soft parts were certain to perish.

It is evident from the remains thus described, that we have in *Hylonomus Lyelli* an animal of lacertian form, with large and stout hind limbs, and somewhat smaller fore limbs, capable of walking and running on land; and though its vertebræ were imperfectly ossified externally, yet the outer walls were sufficiently strong, and their articulation sufficiently firm, to have enabled the creature to erect itself on its hind legs, or to leap. They were certainly proportionately larger and much more firmly knit than those of *Dendrerpeton.* Further, the ribs were long and much curved, and imply a respiration of a higher character than that of modern Batrachians, and consequently a more highly vitalized muscular system. If to these structural points we add the somewhat rounded skull, indicating a large brain, we have before us a creature which, however puzzling in its affinities when anatomically considered, is clearly not to be ranked as low in the scale of creation as modern tailed Batrachians, or even as the frogs and toads. We must add to these also, as important points of difference, the bony scales with which it was armed below, and the ornate appa-

ratus of horny appendages, with which it was clad above. These last, as described in the last section, show that this little animal was not a squalid, slimy dweller in mud, like *Menobranchus* and its allies, but rather a beautiful and sprightly tenant of the coal-formation thickets, vying in brilliancy, and perhaps in colouring, with the insects which it pursued and devoured. Remains of as many as eight or ten individuals have been obtained from three erect Sigillariæ, indicating that these creatures were quite abundant, as well as active and terrestrial in their mode of life.

With respect to the affinities of this species, I think it is abundantly manifest that it presents no close relationship with any reptile hitherto discovered in the Carboniferous system, except perhaps some of the smaller forms in the Permian of Europe, with which Credner and Fritsch have compared it. It is scarcely necessary to say that the characters above described entirely remove this animal from the Labyrinthodonts. Equal difficulties attend the attempt to place it in any other group of recent or extinct Batrachians or proper reptiles. The structures of the skull, and of some points in the vertebræ, certainly resemble those of Batrachians; but, on the other hand, the well-developed ribs, evidently adapted to enlarge the chest in respiration, the pelvis, and the cutaneous covering, are unexampled in modern Batrachians, and assimilate the creature to the true lizards. I have already, in my original description of the animal in 1859, expressed my belief that *Hylonomus* may have had lacertian affinities, but I do not desire to speak too positively in this matter;[1] and thall content myself with stating the following alternatives as to the probable relations of these animals. (1) They may have been true reptiles of low type, and with batrachian tendencies. (2) They may have been representatives of a new family of Batrachians, exhibiting in some points lacertian affinities. (3) They may have

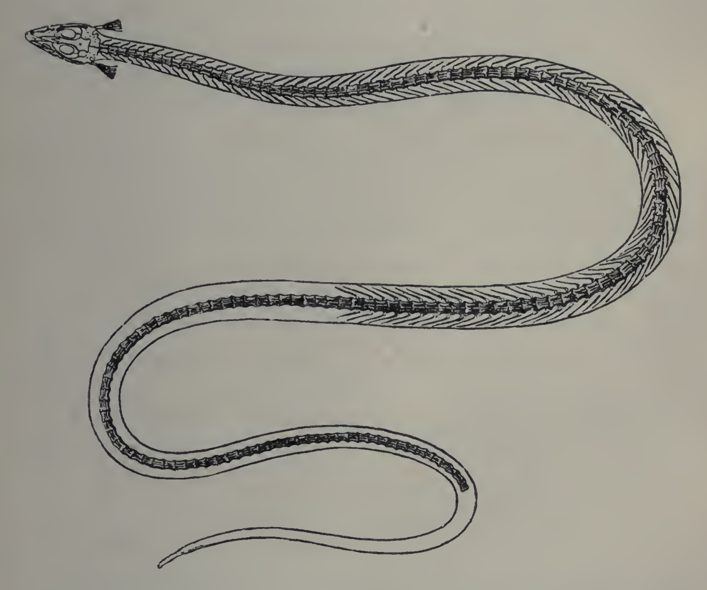
[1] I am glad to say that Fritsch and Credner now lean to the same view.

been the young of some larger reptile, too large and vigorous to be entrapped in the pitfalls presented by the hollow Sigillaria stumps, and in its adult state losing the batrachian peculiarities apparent in the young. Whichever of these views we may adopt, the fact remains, that in the structure of this curious little creature we have peculiarities both batrachian and lacertian, in so far as our experience of modern animals is concerned. It would, however, accord with observed facts in relation to other groups of extinct animals, that the primitive Batrachians of the coal period should embrace in their structures points in after times restricted to the true reptiles. On the other hand, it would equally accord with such facts that the first-born of Lacertians should lean towards a lower type, by which they may have been preceded. My present impression is, that they may constitute a separate family or order, to which I would give the name of MICROSAURIA, and which may be regarded as allied, on the one hand, to certain of the humbler lizards, as the Gecko or Agama, and, on the other, to the tailed Batrachians.

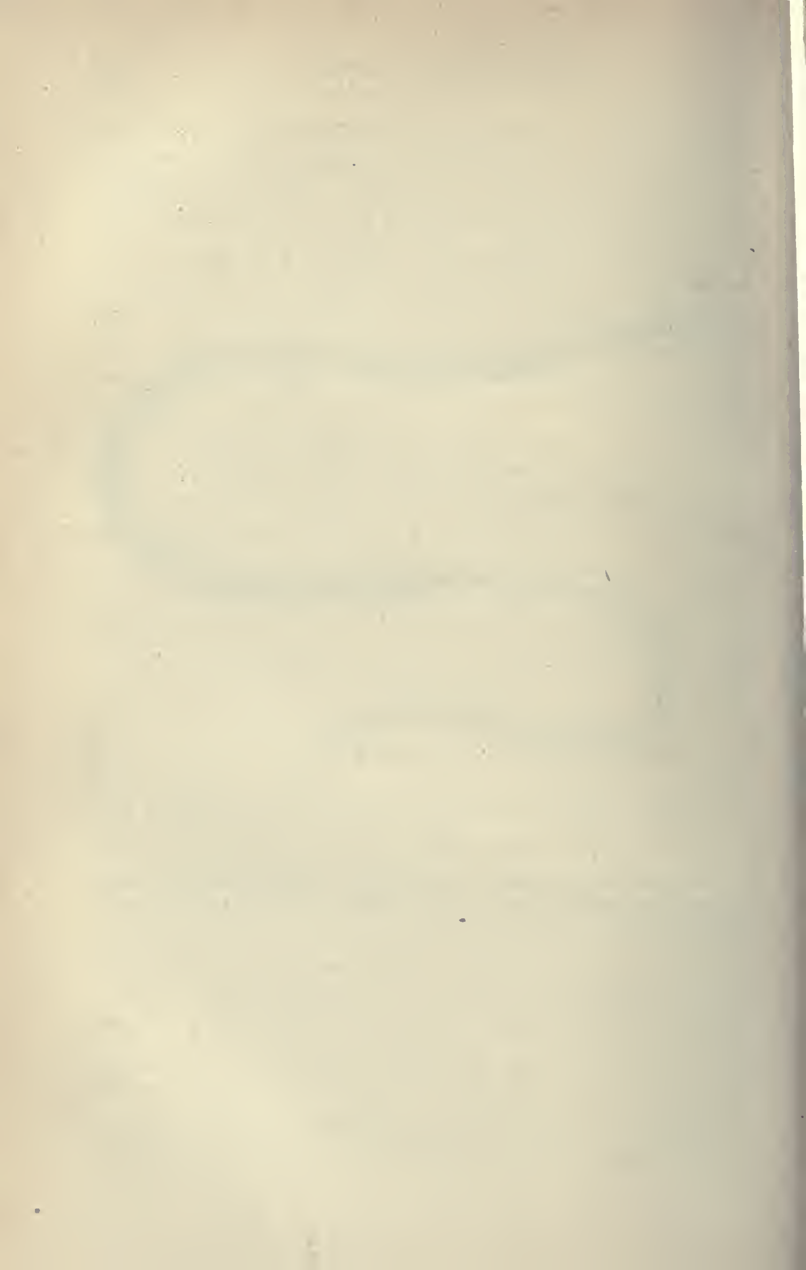
It is likely that *Hylonomus Lyelli* was less aquatic in its habits than *Dendrerpeton*. Its food consisted, apparently, of insects and similar creatures. The teeth would indicate this, and near its bones there are portions of coprolite, containing remains of insects and myriapods. It probably occasionally fell a prey to *Dendrerpeton*, as bones, which may have belonged either to young individuals of this species or to its smaller congener *H. Wymani*, are found in larger coprolites, which may be referred with probability to *Dendrerpeton Acadianum*. This coprolitic matter, which is somewhat plentiful on some of the surfaces in the erect trees, also informs us that the imprisoned animals may in some cases have continued to live for some time, feeding on such animals as may have fallen into their place of confinement, which was destined also to be their tomb. Some other points of interest appear on the

examination of this excrementitious matter. It contains much carbonate of lime, indicating that snails or other mollusks furnished a considerable part of the food of the smaller reptiles. Some portions of it are filled with chitinous fragments, parts of millipedes or insects, but usually so broken up as scarcely to be distinguishable. One curious exception was a part of the head of an insect containing a portion of one of its eyes. The facets of this can be readily seen with the microscope, and are similar to those of modern cockroaches. About 250 of these little eyes are discernible, and they must have been much more numerous. Two points are of interest here: First, the perfection of the compound eye for vision in air. It had long before, in the case of the Trilobites, been used for seeing under water. Secondly, the great age of the still ubiquitous and aggressive family of the cockroaches. In point of fact the oldest known insect, the Protoblattina of the Silurian, is one of these creatures, and they are the most abundant insects in the Carboniferous, so that if they now dispute with us the possession of our food, they may at least put in the claim of prior occupancy of the world. In one mass a quantity of thickish crust or shell appears, which under the microscope presents a minutely tubular and laminated appearance. It may have belonged to some small crustacean or large scorpion on which a *Dendrerpeton* may have been feeding before it fell into the pit in which it was entombed.

In addition to the reptilian species above noticed, the erect trees of Coal Mine Point have afforded several others. There is a second and smaller species of Dendrerpeton (*D. Oweni*) and other forms belonging to the group of Microsauria of which Hylonomus is the type. A second species of that genus (*H. Wymani*) has already been mentioned. A similar creature, but of larger size and with teeth of a wedge or chisel shape, has been referred to a distinct genus, *Smilerpeton*. It seems to have been rare, and the only skeleton found is very imperfect.



Dolichosoma longissimum, a serpentiform Permian Batrachian after Fritsch. This and Hylonomus are opposite or extreme types in regard to general form.



Its teeth are of a form that may have served even for vegetable food, as their sharp edges must have had considerable cutting power. Another curious form of tooth appears in the genus *Hylerpeton.* It has the points worked into oblique grooves separated by sharp edges, which must have greatly aided in piercing tough integument. These creatures seem to have been of stout and robust build, with large limbs. Still another generic type (*Fritschia*) is represented by a species near to Hylonomus in several respects, and with long and beautifully formed limb bones, but with the belly protected with rod-like bodies instead of scales. In this respect Hylerpeton is somewhat intermediate, having long and narrow scales on the belly instead of the oval or roundish scales of Hylonomus. All these last-mentioned forms are Microsaurians, with simple teeth and well-developed ribs and limbs, and smooth cranial bones. Two other species are represented by portions of single skeletons too imperfect to allow them to be certainly determined.

I would emphasize here that the vertebrate animals found in the erect trees are necessarily a selection from the most exclusively terrestrial forms, and from the smaller species of these. The numerous newt-like and serpentiform species found in the shales of the coal formation could not find access to these peculiar repositories, nor could the larger species of the Labyrinthodonts and their allies, even if they were in the habit of occasionally prowling in the forests in search of prey, and this would scarcely be likely, more especially as the waters must have afforded to them much more abundant supplies of food. Of the numerous species figured by Fritsch, Cope and Huxley, only a few approach very near to the forms entrapped in the old hollow Sigillariæ, though several have characters half batrachian and half reptilian.

Invertebrate Air-breathers.

The coal formation rocks have afforded Land Snails, Millipedes, Spiders, Scorpions and Insects, so that all the great types of invertebrate life which up to this day can live on land already had representatives in this ancient period. Some of them, indeed, we can trace further back, the land snails probably to the Devonian, the Millipedes to the same period, and the Scorpions and insects as far as the Silurian. No land vertebrate is yet known, older than the Lower Carboniferous, but there is nothing known to us in physical condition, to preclude the existence of such creatures at least in the Devonian.

It would take us too far afield to attempt to notice the invertebrate land life of the Palæozoic in general. This has been done in great detail by Dr. Scudder. I shall here limit myself to the animals found in our erect trees, and merely touch incidentally on such others as may be connected with them.

I have already mentioned the occurrence of a land snail, a true pulmonate mollusk, in the first find by Lyell and myself at Coal Mine Point, and this was the first animal of this kind known in any rocks older than the Purbeck formation of England. It is one of the groups of so-called Chrysalis-shells, scarcely distinguishable at first sight from some modern West Indian species, and distinctly referable to the modern genus Pupa. It was named *Pupa vetusta*, and a second and smaller species subsequently found was named *P. Bigsbyi*, and a third of different form, and resembling the modern snails, bears the name *Zonites priscus*. The only other Palæozoic land mollusks known at present are a few species found in the coal formation of Ohio, and a fragment supposed to indicate another species from the Devonian plant beds of St. John's, New Brunswick. This last is the oldest known evidence of pulmonate snails. If we ask the precise relations of these creatures to modern snails, it may be answered that of the two leading sub-

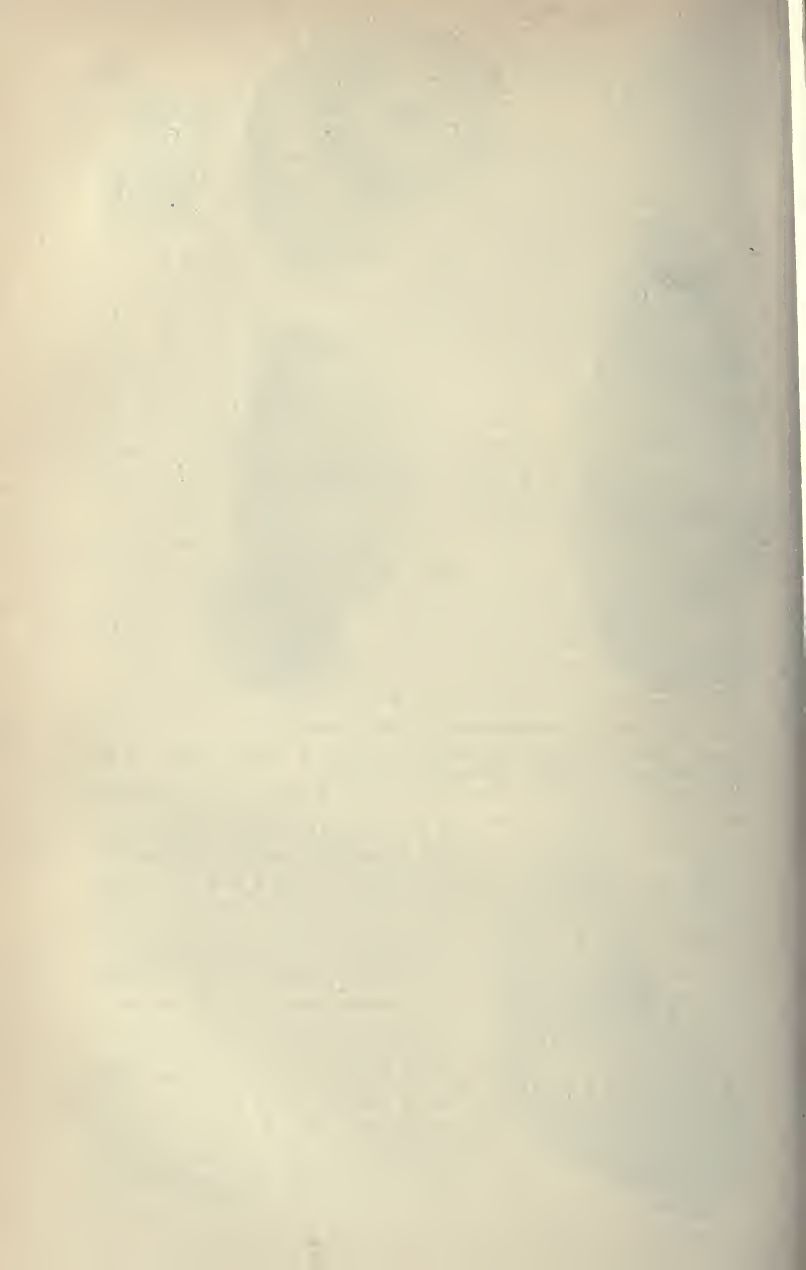
CARBONIFEROUS LAND SNAILS.

Pupa vetusta, Dawson, and *Conulus priscus*, Carpenter, with egg of *Pupa vetusta*—the whole considerably magnified.



A DEVONIAN LAND SNAIL.

I published in 1880, in the *American Journal of Science*, a fragment of what seemed to be a land snail, from the Middle Erian plant beds of St. John, New Brunswick (*Strophia grandæva*, figured here), but have mentioned it with some doubt in the text. Mr. G. F. Matthew has, however, recently communicated to the Royal Society of Canada a second species, found by Mr. W. I. Wilson in the same beds, and which he names *Pupa primæva*. It is accompanied with a scorpion and a millipede. Thus the existence of Land Snails of the Pupa type in the Devonian may be considered as established.



divisions of the group of air-breathing snails (*Pulmonifera*), the Operculate, or those with a movable plate to close the mouth of the shell, and the Inoperculate, or those that are destitute of any such shelly lid or operculum to close the shell, the first has been traced no farther back than the Eocene. The second or inoperculate division, includes some genera that are aquatic and some that are terrestrial. Of the aquatic genera no representatives are known in formations older than the Wealden and Purbeck, and these only in Europe. The terrestrial group, or the family of the *Helicidæ*, which, singularly enough, is that which diverges farthest from the ordinary gill-bearing Gasteropods, is the one which has been traced farthest back, and includes the Palæozoic species. It is further remarkable that a very great gap exists in the geological history of this family. No species are known between the Carboniferous and the early Tertiary, though in the intervening formations there are many fresh-water and estuarine deposits in which such remains might be expected to occur. There is perhaps no reason to doubt the continuance of the Helicidæ through this long portion of geological time, though it is probable that during the interval the family did not increase much in the numbers of its species, more especially as it seems certain that it has its culmination in the modern period, where it is represented by very many and large species, which are dispersed over nearly all parts of our continents.

The mode of occurrence of the Palæozoic Pulmonifera in the few localities where they have been found is characteristic. The earliest known species, *Pupa vetusta*, was found, as already stated, in the material filling the once hollow stem of a Sigillaria at the South Joggins in Nova Scotia, and many additional specimens have subsequently been obtained from similar repositories in the same locality, where they are associated with bones of Batrachians and remains of Millipedes. Other specimens, and also the species *Zonites priscus*, have

been found in a thin, shaly layer, containing *débris* of plants and crusts of Cyprids, and which was probably deposited at the outlet of a small stream flowing through the coal-formation forest. The two species found in Illinois occur, according to Bradley, in an underclay or fossil soil which may have been the bed of a pond or estuary, and subsequently became a forest subsoil. The Erian species occurs in shales charged with remains of land plants, and which must consequently have received abundant drainage from neighbouring land. It is only in such deposits that remains of true land snails can be expected to occur; though, had fresh water or brackish water Pulmonates abounded in the Carboniferous age, their remains should have occurred in those bituminous and calcareo-bituminous shales which contain such vast quantities of *débris* of Cyprids, Lamellibranchs and fishes of the period, mixed with fossil plants.

The specimen first obtained in 1887 having been taken by Sir Charles Lyell to the United States, and submitted to the late Prof. Jeffries Wyman, the shell in question was recognised by him and the late Dr. Gould, of Boston, as a land shell. It was subsequently examined by M. Deshayes and Mr. Gwyn Jeffries, who concurred in this determination; and its microscopic structure was described by the late Prof. Quekett, of London, as similar to that of modern land shells. The single specimen obtained on this occasion was somewhat crushed, and did not show the aperture. Hence the hesitation as to its nature, and the delay in naming it, though it was figured and described in the paper above cited in 1852. Better specimens showing the aperture were afterward obtained by the writer, and it was named and described by him in his "Air-breathers of the Coal Period," in 1863. Owen, in his "Palæontology," subsequently proposed the generic name *Dendropupa*. This I have hesitated to accept, as expressing a generic distinction not warranted by the facts; but should

the shell be considered to require a generic or sub-generic distinction, Owen's name should be adopted for it. There seems, however, nothing to prevent it from being placed in one of the modern sub-genera of simple-lipped Pupæ. With regard to the form of its aperture, I may explain that some currency has been given to an incorrect representation of it, through defective specimens. In the case of delicate shells like this, imbedded in a hard matrix, it is of course difficult to work out the aperture perfectly; and in my published figure in the "Air-breathers," I had to restore somewhat the broken specimens in my possession. This restoration, specimens subsequently found have shown to be very exact.

As already stated, this shell seems closely allied to some modern Pupæ. Perhaps the modern species which approaches most nearly to it in form, markings and size, is *Macrocheilus Gossei* from the West Indies, specimens of which were sent to me some years ago by Mr. Bland, of New York, with the remark that they must be very near to my Carboniferous species. Such edentulous species as *Pupa* (*Leucochila*) *fallax* of Eastern America very closely resemble it; and it was regarded by the late Dr. Carpenter as probably a near ally of those species which are placed by some European conchologists in the genus *Pupilla*.

Pupa vetusta has been found at three distinct levels in the coal formation of the South Joggins. The lowest is the shale above referred to. The next, 1,217 feet higher, is that of the original discovery. The third, 800 feet higher, is in an erect Sigillaria holding no other remains. Thus, this shell has lived in the locality at least during the accumulation of 2,000 feet of beds, including a number of coals and erect forests, as well as beds of bituminous shales and calcareo-bituminous shale, the growth of which must have been very slow.

In the lowest of these three horizons the shells are found, as already stated, in a thin bed of concretionary clay of dark

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grey colour, though associated with reddish beds. It contains *Zonites priscus* as well, though this is very rare, and there are a few valves of *Cythere* and shells of *Naiadites* as well as carbonaceous fragments, fronds of ferns, *Trigonocarpa*, etc. The *Pupæ* are mostly adult, but many very young shells also occur, as well as fragments of broken shells. The bed is evidently a layer of mud deposited in a pond or creek, or at the mouth of a small stream. In modern swamps multitudes of fresh-water shells occur in such places, and it is remarkable that in this case the only Gasteropods are land shells, and these very plentiful, though only in one bed about an inch in thickness. This would seem to imply an absence of fresh-water Pulmonifera. In the erect *Sigillariæ* of the second horizon the shells occur either in a sandy matrix, more or less darkened with vegetable matter, or in a carbonaceous mass composed mainly of vegetable *débris*. Except when crushed or flattened, the shells in these repositories are usually filled with brownish calcite. From this I infer that most of them were alive when imbedded, or at least that they contained the bodies of the animals; and it is not improbable that they sheltered themselves in the hollow trees, as is the habit of many similar animals in modern forests. Their residence in these trees, as well as the characters of their embryology, are illustrated by the occurrence of their mature ova. One of those, which I have considered worth figuring, has been broken in such a way as to show the embryo shell.

They may also have formed part of the food of the reptilian animals whose remains occur with them. In illustration of this I have elsewhere stated that I have found as many as eleven unbroken shells of *Physa heterostropha* in the stomach of a modern *Menobranchus*. I think it certain, however, that both the shells and the reptiles occurring in these trees must have been strictly terrestrial in their habits, as they could not have found admission to the erect trees unless the ground had

been sufficiently dry to allow several feet of the imbedded hollow trunks to be free from water. In the highest of the three horizons the shells occurred in an erect tree, but without any other fossils, and they had apparently been washed in along with a greyish mud.[1]

If we exclude the alleged *Palæorbis* referred to below, all the Palæozoic Pulmonifera hitherto found are American. Since, however, in the Carboniferous age, Batrachians, Arachnidans, Insects and Millipedes occur on both continents, it is not unlikely that ere long European species of land snails will be announced The species hitherto found in Eastern America are in every way strangely isolated. In the plant beds of St. John, about 9,000 feet in thickness, and in the coal formation of the South Joggins, more than 7,000 feet in thickness, no other Gasteropods occur, nor, I believe, do any occur in the beds holding land snails in Illinois. Nor, as already stated, are any of the aquatic Pulmonifera known in the Palæozoic. Thus, in so far as at present known, these Palæozoic snails are separated not only from any predecessors, if there were any, or successors, but from any contemporary animals allied to them.

It is probable that the land snails of the Erian and Carboniferous were neither numerous nor important members of the faunæ of those periods. Had other species existed in any considerable numbers, there is no reason why they should not have been found in the erect trees, or in those shales which contain land plants. More especially would the discovery of any larger species, had they existed, been likely to have occurred. Further, what we know of the vegetation of the Palæozoic period would lead us to infer that it did not abound

[1] The discovery of the shells in this tree was made by Albert I. Hill, C.E. The tree is in Group XXVI. of Division 4 of my Joggins section. The original reptiliferous trees are in Group XV., and the lowest bed in Group VIII.

in those succulent and nutritious leaves and fruits which are most congenial to land snails. It is to be observed, however, that we know little as yet of the upland life of the Erian or Carboniferous. The animal life of the drier parts of the low country is indeed as yet very little known; and but for the revelations in this respect of the erect trees in one bed in the coal formation of Nova Scotia, our knowledge of the land snails and Millipedes, and also of an eminently terrestrial group of reptiles, the *Microsauria*, would have been much more imperfect than it is. We may hope for still further revelations of this kind, and in the meantime it would be premature to speculate as to the affinities of our little group of land snails with animals either their contemporaries or belonging to earlier or later formations, except to note the fact of the little change of form or structure in this type of life in that vast interval of time which separates the Erian period from the present day.

It may be proper to mention here the alleged Pulmonifera of the genus *Palæorbis* described by some German naturalists. These I believe to be worm tubes of the genus *Spirorbis*, and in fact to be nothing else than the common *S. carbonarius* or *S. pusillus* of the coal formation. The history of this error may be stated thus. The eminent palæobotanists Germar, Gœppert and Geinitz have referred the *Spirorbis*, so common in the Coal measures to the fungi, under the name *Gyromyces*, and in this they have been followed by other naturalists, though as long ago as 1868 I had shown that this little organism is not only a calcareous shell, attached by one side to vegetable matters and shells of mollusks, but that it has the microscopic structure characteristic of modern shells of this type.[1] More recently Van Beneden, Cænius, and Goldenberg, perceiving that the fossil is really a calcareous shell, but

[1] "Acadian Geology," 2nd edition, p. 205.

apparently unaware of the observations made in this country by myself and Mr. Lesquereux, have held the *Spirorbis* to be a pulmonate mollusk allied to *Planorbis*, and have supposed that its presence on fossil plants is confirmatory of this view, though the shells are attached by a flattened side to these plants, and are also found attached to shells of bivalves of the genus *Naiadites*. Mr. R. Etheridge, jun., of the Geological Survey of Great Britain, has summed up the evidence as to the true nature of these probably brackish-water shells, and has revised and added to the species, in a series of articles in the *Geological Magazine* of London, vol. viii.

The erect trees of Coal Mine Point are rich in remains of Millipedes. The first of these (*Xylobius Sigillariæ*), which was the first known Palæozoic Myriapod, was described by me from specimens found in a tree extracted in 1852, and this, with a number of other remains subsequently found, was afterwards placed in the hands of Dr. Scudder, who has recognised in the material submitted to him eight species belonging to three genera (*Xylobius*, *Archiulus*, and *Amynilyspes*). These animals in all probability haunted these trees to feed on the decaying wood and other vegetable matter, and were undoubtedly themselves the prey of the Microsaurians. Though these were the earliest known, their discovery was followed by that of many other species in Europe and America, and some of them as old as the Devonian.[1]

The only other remains of Air-breathers found in the erect trees belong to Scorpions, of which some fragments remain in such a state as to make it probable that they have been partially devoured by the imprisoned reptiles. No remains of any aquatic animals have been found in these trees. The

[1] The two first-named genera from the erect trees, according to Scudder, belong to an extinct family of Millipedes, which he names Archiulidæ, and places with other Carboniferous genera in the order *Archipolypoda*. The third belongs to family Euphoberidæ. Proc. R. S. of London, 1892.

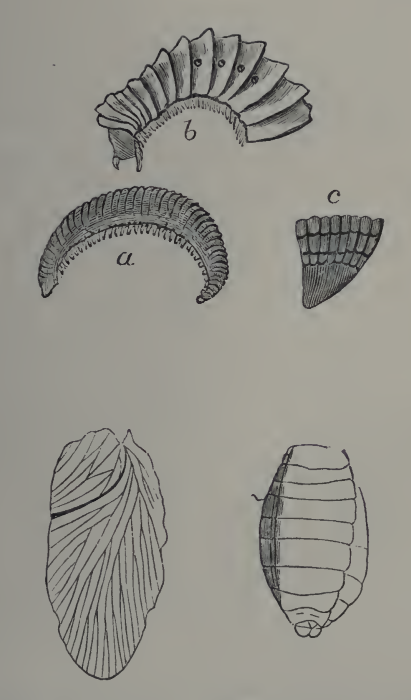
Scorpions are referred by Scudder to three species belonging to two genera.[1]

In the previous paper we have considered the mode of accumulation of Coal, and it may be useful here to note the light thrown on this subject by the Air-breathers of the coal formation and their mode of occurrence.

In no part of the world are the coal measures better developed, or more fully exposed, than in the coast sections of Nova Scotia and Cape Breton; and in these, throughout their whole thickness, no indication has been found of any of the marine fossils of the Lower Carboniferous Limestone. Abundant remains of fishes occur, but these may have frequented estuaries, streams and ponds, and the greater part of them are small ganoids which, like the modern *Lepidosteus* and *Amia*, may have been specially fitted by their semi-reptilian respiration, for the impure waters of swampy districts. Bivalve mollusks also abound; but these are all of the kinds to which I have given the generic name *Naiadites*, and Mr. Salter those of *Anthracomya* and *Anthracoptera*. These shells are all distinct from any known in the marine limestones. Their thin edentulous valves, their structure consisting of a wrinkled epidermis, a thin layer of prismatic shell and an inner layer of imperfectly pearly shell, all remind us of the Anodons and Unios. A slight notch in front concurs with their mode of occurrence in rendering it probable that, like mussels in modern estuaries, they attached themselves to floating or sunken timber. They are thus removed, both in structure and habit, from truly marine species; and may have been fresh-water or brackish-water mussels closely allied to modern Unios.

The crustaceans (*Eurypterus*, *Diplostylus*, *Cyprids*), and the

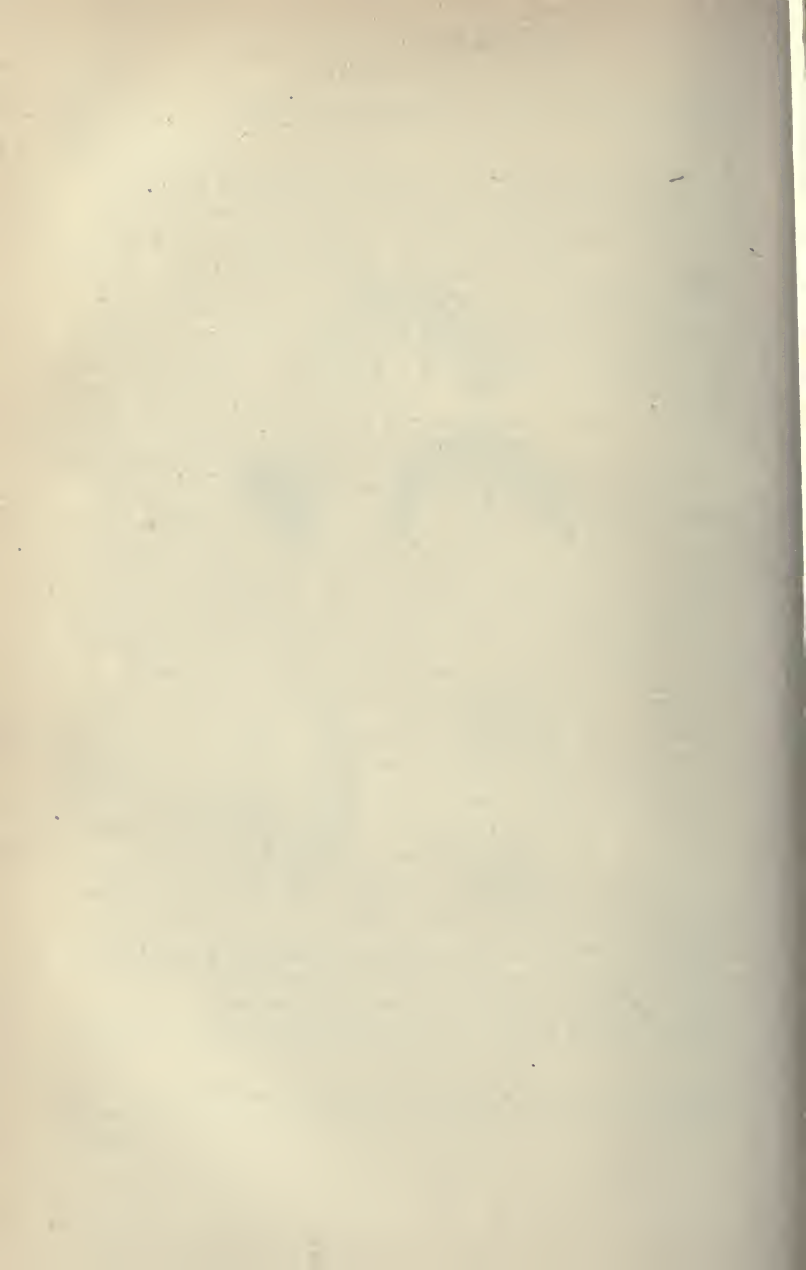
[1] *Mazonia Acadica*, and a second species of *Mazonia*, with fragments of a third species, generally distinct. Proceedings Royal Society of London, 1892.



CARBONIFEROUS MILLIPEDES, *Xylobius Sigillariæ*, Dawson (*a*, *c*), and *Archiulus xylobioides*, Scudder (*b*).

CARBONIFEROUS COCKROACH.—*Blattina Bretonensis*, Sc.

CARBONIFEROUS SCORPION.—*Anthracomartus Carbonarius*, abdominal segments.



worm shell (*Spirorbis*) found with them, are not necessarily marine, though some of them belonged probably to brackish water, and they have not yet been found in those carboniferous beds deposited in the open sea. There is thus in the whole thickness of the middle coal measures of Nova Scotia a remarkable absence at least of open sea animals; and if, as is quite probable, the sea inundated at intervals the areas of coal accumulation, the waters must have been shallow, and to a great extent land-locked, so that brackish-water rather than marine animals inhabited them.

On the other hand, there are in these coal measures abundant evidences of land surfaces; and subaërial decay of vegetable matter in large quantity is proved by the occurrence of the mineral charcoal of the coal itself, as I have elsewhere shown.[1] The erect trees which occur at so many levels also imply subaërial decay. A tree imbedded in sediment and remaining under water, could not decay so as to become hollow and deposit the remains of its wood in the state of mineral charcoal within the hollow bark. Yet this is the case with the greater part of the erect Sigillariæ which occur at more than twenty levels in the Joggins section. Nor could such hollow trunks become repositories for millipedes, snails and reptiles, if under water. On the other hand, if, as seems necessary to explain the character of the reptiliferous erect trees, these remained dry, or nearly so, in the interior, this would imply not merely a soil out of water, but comparatively well drained; as would indeed always be the case, when a flat resting on a sandy subsoil was raised several feet above the level of the water. Further, though the peculiar character of the roots of *Sigillariæ* and *Calamites* may lend some countenance to the supposition that they could grow under water, or in water-soaked soils, this will not apply to coniferous trees, to

[1] *Journal of Geological Survey*, vol. xv.

ferns, and other plants, which are found under circumstances which show that they grew with the *Sigillariæ.*

In the coal measures of Nova Scotia, therefore, while marine conditions are absent, there are ample evidences of fresh-water or brackish-water conditions, and of land surfaces, suitable for the air-breathing animals of the period. Nor do I believe that the coal measures of Nova Scotia were exceptional in this respect. It is true that in Great Britain evidences of marine life do occur in the coal measures; but not, so far as I am aware, in circumstances which justify the inference that the coal is of marine origin. Alternations of marine and land remains, and even mixtures of these, are frequent in modern submarine forests. When we find, as at Fort Lawrence in Nova Scotia, a modern forest rooted in upland soil forty feet below high-water mark,[1] and covered with mud containing living Tellinas and Myas, we are not justified in inferring that this forest grew in the sea. We rather infer that subsidence has occurred. In modern salt marshes it is not unusual to find every little runnel or pool full of marine shell fish, while in the higher parts of the marsh land plants are growing; and in such places the deposit formed must contain a mixture of land plants and marine animals with salt grasses and herbage —the whole *in situ.*[2]

These considerations serve, I think, to explain all the apparently anomalous associations of coal plants with marine fossils; and I do not know any other arguments of apparent weight that can be adduced in favour of the marine or even

[1] *Journal of Geological Society*, vol. xi.

[2] In the marshes at the mouth of Scarborough River, in Maine, channels not more than a foot wide, and far from the sea, are full of Mussels and Myæ; and in little pools communicating with these channels there are often many young *Limuli*, which seem to prefer such places, and the cast-off shells and other remains of which may become imbedded in mud and mixed with land plants, just as in the shales of the coal measures.

aquatic origin of coal, except such as are based on misconceptions of the structure and mode of growth of sigillaroid trees and of the stratigraphical relations of the coal itself.[1] It is to be observed, however, that while I must maintain the essentially terrestrial character of the ordinary coal and of its plants, I have elsewhere admitted that cannel coals and earthy bitumen present evidences of subaquatic deposition; and have also abundantly illustrated the facts that the coal plants grew on swampy flats, liable not only to river inundations, but also to subsidence and submergence.[2] In the oscillation of these conditions it is evident that *Sigillariæ* and their contemporaries must often have been placed in conditions unfavourable or fatal to them, and when their remains are preserved to us in these conditions, we may form very incorrect inferences as to their mode of life. Further, it is to be observed that the conditions of submergence and silting up which were favourable to the preservation of specimens of *Sigillariæ* as fossils, must have been precisely those which

[1] It is unfortunate that few writers on this subject have combined with the knowledge of the geological features of the coal a sufficient acquaintance with the phenomena of modern marshes and swamps, and with the conditions necessary for the growth of plants such as those of the coal. It would be easy to show, were this a proper place to do so, that the "swells," "rock faults," splitting of beds, and other appearances of coal seams quite accord with the theory of swamp accumulation; that the plants associated with *Sigillariæ* could not have lived with their roots immersed in salt water; that the chemical character of the underclays implies drainage and other conditions impossible under the sea; that the composition and minute structure of the coal are incompatible with the supposition that it is a deposit from water, and especially from salt water; and that it would be more natural to invoke wind driftage as a mode of accumulation for some of the sandstones, than water driftage for the formation of the coal. At the same time it is pretty certain that such beds as the cannels and earthy bitumens which appear to consist of finely comminuted vegetable matter, without mineral charcoal, may have been deposits of muck in shallow lakes or lagoons.

[2] *Journal of Geol. Socy.*, vols. x. and xv., and "Acadian Geology."

were destructive to them as living plants ; and on the contrary, that the conditions in which these forests may have flourished for centuries must have been those in which there was little chance of their remains being preserved to us, in any other condition at least than that of coal, which reveals only to careful microscopic examination the circumstances, whether aërial or aquatic, under which it was formed.

It is also noticeable that, in conditions such as those of the coal formation, it would be likely that some plants would be specially adapted to occupy newly emerged flats and places liable to inundation and silting up. I believe that many of the *Sigillariæ*, and still more eminently the *Calamites*, were suitable to such stations. There is direct evidence that the nuts named Trigonocarpa were drifted extensively by water over submerged flats of mud. Many *Cardiocarpa* were winged seeds which may have drifted in the air. The Calamites may, like modern *Equiseta*, have produced spores with elaters capable of floating them in the wind. One of the thinner coals at the Joggins is filled with spores or spore cases that seem to have carried hairs on their surfaces, and may have been suited to such a mode of dissemination. I have elsewhere proved[1] that at least some species of *Calamites* were, by their mode of growth, admirably fitted for growing amid accumulating sediment, and for promoting its accumulation.

The reptiles of the coal formation are probably the oldest known to us, and possibly, though this we cannot affirm, the highest products of creation in this period. Supposing, for the moment, that they are the highest animals of their time, and, what is perhaps less likely, that those which we know are a fair average of the rest, we have the curious fact that they are all carnivorous, and the greater part of them fitted to find food in the water as well as on the land. The plant feeders of the period, on the land at least, are all invertebrates, as snails,

[1] "Acadian Geology," chapter on Coal Plants.

millipedes, and perhaps insects. The air-breathing vertebrates are not intended to consume the exuberant vegetable growth, but to check the increase of its animal enemies. Plant life would thus seem to have had in every way the advantage. The millipedes probably fed only on roots and decaying substances, the snails on the more juicy and succulent plants growing in the shadow of the woods, and the great predominance of the family of cockroaches among carboniferous insects points to similar conclusions as to that class. While, moreover, the vegetation of the coal swamps was most abundant, it was not, on the whole, of a character to lead us to suppose that it supported many animals. Our knowledge of the flora of the coal swamps is sufficiently complete to exclude from them any abundance of the higher phænogamous plants. We know little, it is true, of the flora of the uplands of the period; but when we speak of the coal-formation land, it is to the flats only that we refer. The foliage of the plants on these flats with the exception of that of the ferns, was harsh and meagre, and there seem to have been no grasses or other nutritious herbaceous plants. These are wants of themselves likely to exclude many of the higher forms of herbivorous life. On the other hand, there was a profusion of large nut-like seeds, which in a modern forest would probably have afforded subsistence to squirrels and similar animals. The pith and thick soft bark of many of the trees must at certain seasons have contained much nutritive matter, while there was certainly sufficient material for all those insects whose larvæ feed on living and dead timber, as well as for the creatures that in turn prey on them. It is remarkable that there seem to have been no vertebrate animals fitted to avail themselves of these vast stores of food. The question: "What may have fed on all this vegetation?" was never absent from my mind in all my explorations of the Nova Scotia coal sections; but no trace of any creature other than those already mentioned has ever rewarded my search. In

Nova Scotia it would seem that a few snails, gally-worms, and insects were the sole links of connection between the plant creation and air-breathing vertebrates. Is this due to the paucity of the fauna, or the imperfection of the record? The fact that a few erect stumps have revealed nearly all the air-breathers yet found, argues strongly for the latter cause; but there are some facts bearing on the other side.

A gally-worm, if, like its modern relatives, hiding in crevices of wood in forests, was one of the least likely animals to be found in aqueous deposits. The erect trees gave it its almost sole chance of preservation. *Pupa vetusta* is a small species, and its shell very thin and fragile, while it probably lived among thick vegetation. Further, the measures 2,000 feet thick, separating the lowest and highest beds in which it occurs, include twenty-one coal seams, having an aggregate thickness of about twenty feet, three beds of bituminous limestone of animal origin, and perhaps twenty beds holding *Stigmaria in situ*, or *erect Sigillariæ* and *Calamites*. The lapse of time implied by this succession of beds, many of them necessarily of very slow deposition, must be very great, though it would be mere guess work to attempt to resolve it into years. Yet long though this interval must have been, *Pupa vetusta* lasted without one iota of change through it all; and, more remarkable still, was not accompanied by more than two other species of its family. Where so many specimens occur, and in situations so diverse, without any additional species, the inference is strong that no other of similar habits existed. If in any of those subtropical islands, whose climate and productions somewhat resemble those of the coal period, after searching in and about decaying trees, and also on the bars upon which rivers and lakes drifted their burdens of shells, we should find only three species, but one of these in very great numbers, we would surely conclude that other species, if present, were very rare.

Again, footprints referable to *Dendrerpeton*, or similar animals,

occur in the lower Carboniferous beds below the marine limestones, in the middle coal measures, and in the upper coal formation, separated by a thickness of beds which may be estimated at 15,000 feet, and certainly representing a vast lapse of time. Did we know the creature by these impressions alone, we might infer its continued existence for all this great length of time; but when we also find its bones in the principal repositories of reptile remains, and in company with the other creatures found with it, we satisfy ourselves that of them all it was the most likely to have left its trail in the mud flats. We thus have reason to conclude that it existed alone during this period, in so far as its especial kind of habitat was concerned; though there lived with it other reptiles, some of which, haunting principally the woods, and others the water, were less likely to leave impressions of their footprints. These may be but slight indications of truth, but they convey strong impressions of the persistence of species, and also of the paucity of species belonging to these tribes at the time.

If we could affirm that the Air-breathers of the coal period were really the first species of their families, they might acquire additional interest by their bearing on this question of origin of species. We cannot affirm this; but it may be a harmless and not uninstructive play of fancy to suppose for a moment that they actually are so, and to inquire on this supposition as to the mode of their introduction. Looking at them from this point of view, we shall first be struck with the fact that they belong to all of the three great leading types of animals which include our modern Air-breathers—the Vertebrates, the Arthropods, and the Mollusks. We have besides to consider in this connection that the breathing organs of an insect are air tubes opening laterally (tracheæ), those of a land snail merely a modification of the chamber which in marine species holds the gills, while those of the reptiles represent the air bladder of the fishes. Thus, in the three groups the breathing organs are

quite distinct in their nature and affinities. This at once excludes the supposition that they can all have been derived from each other within the limits of the coal period. No transmutationist can have the hardihood to assert the convertibility, by any direct method, of a snail into a millipede or an insect, or of either into a reptile. The plan of structure in these creatures is not only different, but contrasted in its most essential features. It would be far more natural to suppose that these animals sprang from aquatic species of their respective types. We should then seek for the ancestors of the snail in aquatic Gasteropods, for those of the millipede in worms or Crustaceans, and for those of the reptiles in the fishes of the period. It would be easy to build up an imaginary series of stages, on the principle of natural selection, whereby these results might be effected ; but the hypothesis would be destitute of any support from fact, and would be beset by more difficulties than it removes. Why should the result of the transformation of water snails breathing by gills be a *Pupa?* Would it not much more likely be an *Auricula* or a *Limnea?* It will not solve this difficulty to say that the intermediate forms became extinct, and so are lost. On the contrary, they exist to this day, though they were not, in so far as we know, introduced so early. But negative evidence must not be relied on; the record is very imperfect, and such creatures may have existed, though unknown to us. It may be answered that they could not have existed in any considerable numbers, else some of their shells would have appeared in the coal-formation beds, so rich in crustaceans and bivalve mollusks. Further, the little Pupa remained unchanged during a very long time, and shows no tendency to resolve itself into anything higher, or to descend to anything lower, while in the lowest bed in which it occurs it is associated with a round snail of quite different type. Here, if anywhere, in what appears to be the first introduction of air-breathing invertebrates, we should be able to find the

evidences of transition from the gills of the Prosobranchiate and the Crustacean to the air sac of the Pulmonate and the tracheæ of the millipede. It is also to be observed that many other structural changes are involved, the aggregate of which makes a Pulmonate or a millipede different in every particular from its nearest allies among gill-bearing Gasteropods or Crustaceans.

It may be said, however, that the links of connection between the coal reptiles and fishes are better established. All the known coal reptiles have leanings to the fishes in certain characters; and in some, as in *Archegosaurus*, these are very close. Still the interval to be bridged over is wide, and the differences are by no means those which we should expect. Were the problem given to convert a ganoid fish into an *Archegosaurus* or *Dendrerpeton*, we should be disposed to retain unchanged such characters as would be suited to the new habits of the creature, and to change only those directly related to the objects in view. We should probably give little attention to differences in the arrangement of skull bones, in the parts of the vertebræ, in the external clothing, in the microscopic structure of the bone, and other peculiarities for serving similar purposes by organs on a different plan, which are so conspicuous so soon as we pass from the fish to the Batrachian. It is not, in short, an improvement of the organs of the fish that we witness so much as the introduction of new organs.[1] The foot of the batrachian bears, perhaps, as close a relation to the fin of the fish as the screw of one steamship to the paddle wheel of another, or as the latter to a carriage wheel; and can be just as rationally supposed to be not a new instrument, but the old one changed. In this connection even a footprint in the sand startles us as much as that of Friday did Robinson

[1] An ingenious attempt by Prof. Cope, to deduce the batrachian foot from the fins of certain carboniferous fishes, will be found in the *Proceedings of the Philos. Academy of Philadelphia* for the present year.

Crusoe. We see five fingers and toes, and ask how this numerical arrangement started at once from fin rays of fishes all over the world; and how it has continued unchanged till now, when it forms the basis of our decimal arithmetic.

Again, our reptiles of the coal do not constitute a continuous series, and belong to a great number of distinct genera and families, nor is it possible that they can all, except at widely different times, have originated from the same source. It either happened, for some unknown reason, that many kinds of fishes put on the reptilian guise in the same period, or else the vast lapse of ages required for the production of a reptile from a fish must be indefinitely increased for the production of many dissimilar reptiles from each other; or, on the other hand, we must suppose that the limit between the fish and reptile being once overpassed, a facility for comparatively rapid changes became the property of the latter. Either supposition would, I think, contradict such facts bearing on the subject as are known to us.

We commenced with supposing that the reptiles of the Coal might possibly be the first of their family, but it is evident from the above considerations, that on the doctrine of natural selection, the number and variety of reptiles in this period would imply that their predecessors in this form must have existed from a time as early as any in which even fishes are known to exist; so that if we adopt any hypothesis of derivation, it would probably be necessary to have recourse to that which supposes at particular periods a sudden and as yet unaccountable transmutation of one form into another; a view which, in its remoteness from anything included under ordinary natural laws, does not materially differ from that currently received idea of creative intervention, with which, in so far as our coal reptiles can inform us, we are for the present satisfied.

There is one other point which strikes the naturalist in considering these animals, and which has a certain bearing on such

hypothesis. It is the combination of various grades of reptilian types in these ancient creatures. It has been well remarked by Hugh Miller, and more fully by Agassiz, that this is characteristic of the first appearance of new groups of animals. Now selection, as it acts in the hands of the breeder, tends to specialization; and natural selection, if there is such a thing, is supposed to tend in the same direction. But when some distinctly new form is to be introduced, an opposite tendency seems to prevail, a sort of aggregation in one species of characters afterward to be separated and manifested in distinct groups of creatures. The introduction of such new types also tends to degrade and deprive of their higher properties previously existing groups of lower rank. It is easy to perceive in all this, law and order, in that higher sense in which these terms express the will and plan of the Supreme Mind, but not in that lower sense in which they represent the insensate operation of blind natural forces.

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MARKINGS, FOOTPRINTS AND FUCOIDS.

DEDICATED TO THE MEMORY OF THE LATE

DR. J. J. BIGSBY, F.R.S.,

OF LONDON,

THE PAINSTAKING AND ACCURATE AUTHOR

OF THE THESAURUS SILURICUS AND DEVONICO-CARBONIFERUS,

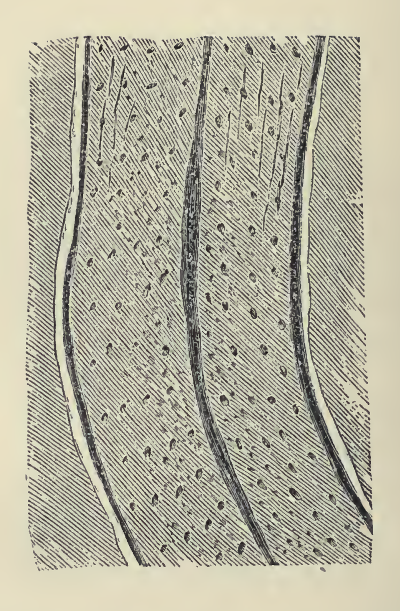
A WARM AND KIND FRIEND AND CHRISTIAN GENTLEMAN

AND ONE OF THE

PIONEERS OF CANADIAN GEOLOGY.

Reminiscences of Lyell's Work—Tidal Flats of the Bay of Fundy—Rill Marks and Shrinkage Cracks —Worm Trails and Burrows—The Paces of Limulus—Fucoids versus Trails—Footprints of Vertebrates





TRACK OF LIMULUS.—Modern, Orchard Beach.
Showing its resemblance to the *Protichnites* of the Cambrian. (Page 320.)

CHAPTER XI.

MARKINGS, FOOTPRINTS AND FUCOIDS.

I BELIEVE my attention was first directed to the markings made by animals on the surfaces of rocks, when travelling with the late Sir Charles Lyell in Nova Scotia, in 1842. He noticed with the greatest interest the trails of worms, insects, and various other creatures, and the footprints of birds on the surface of the soft red tidal mud of the Bay of Fundy, and subsequently published his notes on the various markings in these deposits in his "Travels in North America," and in a paper presented to the Geological Society of London. I well remember how, in walking along the edge of the muddy shore, he stopped to watch the efforts of a grasshopper that had leaped into the soft ooze, and was painfully making a most complicated trail in his effort to escape. Sir Charles remarked that if it had been so fortunate as to make these strange and complicated tracks on some old formation now hardened into stone and buried in the earth, it might have given occasion to much learned discussion.

At a later period I found myself perplexed in the study of fossil plants by the evident errors of many palæobotanists unacquainted with modern markings on shores, in referring all kinds of mere markings to the vegetable kingdom, and especially to the group of fucoids or seaweeds, which had become a refuge for destitute objects not referable to other kinds of fossils. It thus became necessary to collect and study these objects, as they existed in rocks of different ages, and to com-

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pare them with the examples afforded by the modern beach; and perhaps no locality could have afforded better opportunities for this than the immense tidal flats of the finest mud left bare by the great tides of the Bay of Fundy in Nova Scotia. At a more recent period still, the subject has come into great prominence in Europe, and if we are to gauge its importance by the magnitude of the costly illustrated works devoted to it by Delgado, Saporta, Nathorst, and others, and the multitude of scattered papers in scientific periodicals, we should regard it as one of the most salient points in Geology.[1]

It may be well further to introduce the subject by a few extracts from Lyell's work above referred to.

"The sediment with which the waters are charged is extremely fine, being derived from the destruction of cliffs of red sandstone and shale, belonging chiefly to the coal measures. On the borders of even the smallest estuaries communicating with a bay, in which the tides rise sixty feet and upwards, large areas are laid dry for nearly a fortnight between the spring and neap tides, and the mud is then baked in summer by a hot sun, so that it becomes solidified and traversed by cracks caused by shrinkage. Portions of the hardened mud may then be taken up and removed without injury. On examining the edges of each slab we observe numerous layers, formed by successive tides, usually very thin, sometimes only one-tenth of an inch thick, of unequal thickness, however, because, according to Dr. Webster, the night tides rising a foot higher than the day tides throw down more sediment. When a shower of rain falls, the highest portion of the mud-covered flat is usually too hard to receive any impressions; while that recently uncovered by the tide, near the water's edge, is too soft. Between these areas a zone occurs almost as smooth and even as a looking-glass, on which every drop forms a cavity of circular or oval form; and if the shower be

[1] *Journal of London Geological Society*, vol. vii. p. 239.

transient, these pits retain their shape permanently, being dried by the sun, and being then too firm to be effaced by the action of the succeeding tide, which deposits upon them a new layer of mud. Hence we find, on splitting open a slab an inch or more thick, on the upper surface of which the marks of recent rain occur, that an inferior layer, deposited perhaps ten or fourteen tides previously, exhibits on its under surface perfect casts of rain prints which stand out in relief, the moulds of the same being seen in the layer below."

After mentioning that a continued shower of rain obliterates the more regular impressions, and produces merely a blistered or uneven surface, and describing minutely the characteristics of true rain marks in their most perfect state, Sir Charles adds :—

"On some of the specimens the winding tubular tracks of worms are seen, which have been bored just beneath the surface. Sometimes the worms have dived beneath the surface, and then re-appeared. Occasionally the same mud is traversed by the footprints of birds (*Tringa minuta*), and of musk-rats, minks, dogs, sheep and cats. The leaves also of the elm, maple and oak trees have been scattered by the winds over the soft mud, and having been buried under the deposits of succeeding tides, are found on dividing the layers. When the leaves themselves are removed, very faithful impressions, not only of their outline, but of their minutest veins, are left imprinted on the clay."

This is a minor illustration of that application of recent causes to explain ancient effects of which the great English geologist was the apostle and advocate, and which he so admirably practised in his own work. It is also an illustration of the fact that things the most perishable and evanescent may, when buried in the crust of the earth, become its most durable monuments. Footprints in the sand of the tidal shore are in the ordinary course of events certain to be obliterated

by the next tide; but when carefully filled up by gently deposited new material, and hardened into stone, there is no limit to their duration.

Let us inquire how this may take place, and the tidal flats of the Bay of Fundy and Basin of Minas may supply us with the information desired. In the upper parts of the Bay of Fundy and its estuaries the rise and fall of tide, as is well known, are excessive. I quote the following description of the appearance they present from a work of earlier date :—

"The tide wave that sweeps to the north-east, along the Atlantic coast of the United States, entering the funnel-like mouth of the Bay of Fundy, becomes compressed and elevated, as the sides of the bay gradually approach each other, until in the narrower parts the water runs at the rate of six or seven miles per hour, and the vertical rise of the tide amounts to sixty feet or more. In Cobequid and Chiegnecto Bays these tides, to an unaccustomed spectator, have rather the aspect of some rare convulsion of nature than of an ordinary daily phenomenon. At low tide wide flats of brown mud are seen to extend for miles, as if the sea had altogether retired from its bed; and the distant channel appears as a mere strip of muddy water. At the commencement of flood a slight ripple is seen to break over the edge of the flats. It rushes swiftly forward, and, covering the lower flats almost instantaneously, gains rapidly on the higher swells of mud, which appear as if they were being dissolved in the turbid waters. At the same time the torrent of red water enters all the channels, creeks and estuaries; surging, whirling, and foaming, and often having in its front a white, breaking wave, or 'bore,' which runs steadily forward, meeting and swallowing up the remains of the ebb still trickling down the channels. The mud flats are soon covered; and then, as the stranger sees the water gaining with noiseless and steady rapidity on the steep sides of banks and cliffs, a sense of insecurity creeps over him, as if no limit

could be set to the advancing deluge. In a little time, however, he sees that the fiat, 'Hitherto shalt thou come, and no farther,' has been issued to the great bay tide: its retreat commences, and the waters rush back as rapidly as they entered.

"The rising tide sweeps away the fine material from every exposed bank and cliff, and becomes loaded with mud and extremely fine sand, which, as it stagnates at high water, it deposits in a thin layer on the surface of the flats. This layer, which may vary in thickness from a quarter of an inch to a quarter of a line, is coarser and thicker at the outer edge of the flats than nearer the shore; and hence these flats, as well as the marshes, are usually higher near the channels than at their inner edge. From the same cause,—the more rapid deposition of the coarser sediment,—the lower side of each layer is arenaceous, and sometimes dotted over with films of mica, while the upper side is fine and slimy, and when dry has a shining and polished surface. The falling tide has little effect on these deposits, and hence the gradual growth of the flats, until they reach such a height that they can be overflowed only by the high spring tides. They then become natural or salt marsh, covered with the coarse grasses and *carices* which grow in such places. So far the process is carried on by the hand of nature; and before the colonization of Nova Scotia, there were large tracts of this grassy alluvium to excite the wonder and delight of the first settlers on the shores of the Bay of Fundy. Man, however, carries the land-making process farther; and by diking and draining, excludes the sea water, and produces a soil capable of yielding for an indefinite period, without manure, the most valuable cultivated grains and grasses."

The mud of these great tidal flats is at the surface of a red colour, and so fine that when the tide leaves it and its surface becomes dry, it shines in the sun as if polished. It is thus capable of taking the finest impressions. When the tide is in,

numerous small fish of various species occupy the ground and may leave marks of their fins and tails as they gambol or seek their food. Shell fishes, worms, and Crustaceans scramble over the same surface, or make burrows in it. As the tide recedes flocks of sandpipers and crows follow it down, and leave an infinity of footprints, and even quadrupeds like the domestic hog go far out at low water in search of food. It is said that in some parts of the Bay the hogs are so assiduous in this pursuit that they even awake and go out on the flats in the night tide, and that they have so learned to dread the dangers of the flood, that when in the darkness they hear the dull sound of the approaching bore, they squeal with fear and rush madly for the shore.

If we examine it minutely, we shall find that the tidal deposit is laminated. The tidal water is red and muddy, and holds in suspension sediment of various degrees of coarseness. This, undergoes a certain process of levigation. In the first run of the flood the coarser material falls to the bottom. As its force diminishes the finer material is deposited, and at full tide, when the current has ceased, the finest of all settles, forming a delicate coat of the purest and most tenacious clay. Thus, if a block of the material is taken up and allowed to dry, it tends to separate into thin laminæ, each of which represents a tide, and is somewhat sandy below, and passes into the finest moulding clay above. The tracks and impressions preserved are naturally made on the last or finest deposit, and filled in with the coarser or more sandy of the next tide. But this may take place in different ways. Impressions made under water at flood tide, or on the surface left bare by the ebb, may in favourable localities be sufficiently tenacious or firm to resist the abrading action of the flood, and may thus be covered and preserved by the next layer, and in this way they may be seen on splitting up a block of the dried mud. But in shallow places and near the shore, where the deposit

has time to consolidate and become dried by the sun and air before the next tide, much better impressions are preserved; and lastly, on those parts of the shore which are reached only by the spring tides, the mud of the highest tide of course may have several days to harden before the next tide reaches it, and in this case it becomes cracked by an infinity of shrinkage cracks, which, when it is next covered with the tide, are filled with new sediment. In this way is produced in great perfection that combination of footprints, or even of impressions of rain, with casts of cracks, which is so often seen in the older rocks. Where on the sides of channels or near the shore the mud has a considerable slope, another and very curious effect results. As the tide ebbs the water drains off the surface, or oozing out of the wet sand and mud, forms at the top of the bank minute grooves often no larger than fine threads. These coalesce and form small channels, and these, again, larger ones, till at low tide the whole sloping surface is seen to be covered with a smooth and beautiful tracery resembling the rivers on a map, or the impressions of the trunks and branches of trees, or the fronds of gigantic seaweeds. These "rill marks," as they have been called, are found in great abundance in the coal formation and triassic sandstones and shales, and I am sorry to say, have often been named and described as Fucoids, and illustrated by sumptuous plates. Sometimes these impressions are so fine as to resemble the venation of leaves, sometimes so large as to simulate trees, and I have even seen them complicated with shrinkage cracks, the edges of which were minutely crenulated by little rills running into them from the surface.

It is further to be noticed that all these markings and impressions on tidal shores may, when covered by succeeding deposits, appear either in intaglio or relief. On the upper surface they are of course sunken, but on the lower surface of the bed deposited on them they are in relief. It often happens

also that these casts in relief are the best preserved. This arises from the fact that the original moulds or impressions are usually made in clay, whereas the filling material is sandy, and the latter, infiltrated with calcareous or siliceous matter, may become a hard sandstone, while the clay may remain a comparatively soft shale. This tendency of casts rather than of moulds to be preserved sometimes produces puzzling effects. A cylindrical or branching trail thus often assumes the appearance of a stem, and any pits or marginal impressions assume the form of projections or leaves, and thus a trail of a worm or Gastropod or a rill mark may easily simulate a plant. It is to be observed, however, that these prominent casts are on the under side of the beds, that their material is continuous with that of the beds to which they belong, and that they are destitute of any carbonaceous matter. There are, however, cases where markings may be in relief, even on the upper surfaces of beds. The following are illustrations of this. Just as a man walking in newly fallen snow compresses it under his feet, and if the snow be afterwards drifted away or melted away by the sun, the compressed part resists longest, and may appear as a raised footmark, so tracks made on soft material may consolidate it so that if the soft mud be afterwards washed away the tracks may remain projecting. Again, worms eject earthy matter from their burrows, forming mounds, patches or raised ridges of various forms on the surface, and some animals burrow immediately under the surface, pushing up the mud over them into a ridge, while others pile up over their bodies pellets of clay, forming an archway or tunnel as they go. Zeiller has shown that the mole cricket forms curious roofed trails of this kind, and it seems certain that Crustaceans and marine worms of different kinds execute similar works, and that their roofed burrows, either entire or fallen in, produce curious imitations of branches of plants.

The great and multiform army of the sea worms is indeed

the most prolific source of markings on sea-formed rocks. Sometimes they cover very large surfaces of these, or penetrate the beds as perforations, with tortuous furrows, or holes perfectly simple, or marked with little striæ made by bristles or minute feet, sometimes with a fringe of little footmarks a each side, sometimes with transverse furrows indicating the joints of the animal's body. Multitudes of these markings have been described and named either as plants or as worm-tracks. Again, these creatures execute subterranean burrows, sometimes vertical, sometimes tortuous. These are often mere cylindrical holes afterwards filled with sand, but sometimes they have been lined with a membranous tube, or with the rejectamenta of the food of the animals, or with little fragments of organic matter cemented together. Sometimes they open on the surface as simple apertures, but again they may be surrounded with heaps of castings, sometimes spiral in form, or with dumps of sand produced in their excavation, and which may assume various forms, according to circumstances. Sometimes the aperture is double, so that they seem to be in pairs. Sometimes, for the convenience of the animal, the aperture is widened into the form of a funnel, and sometimes the creature, by extending its body and drawing it in, surrounds its burrow with a series of radiating tracks simulating the form of a starfish or sea anemone, or of the diverging branches of a plant.

Creatures of higher grade, provided with jointed limbs, naturally make their actions known in more complicated ways. Some years ago I had the pleasure of spending a few weeks at the favourite sea-side resort of Orchard Beach on the New England coast, and there made my first acquaintance with that very ancient and curious creature the Limulus, or Horse-shoe Crab, or King-crab, as it is sometimes called. Orchard Beach is, I presume, near its northern range on our coast, and the specimens seen were not very large in size, though by no means

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rare, and not infrequently cast on shore in storms. But the best facilities for studying their habits were found in a marsh at no great distance from the hotel, where there were numerous channels, ditches and little ponds filled with sea water at high tide. In these were multitudes of young Limuli, varying from an inch to three or four inches in breadth, and though many were dead or merely cast shells, it was easy to take young specimens with a landing net. A number of these were secured, and I made it my business for some time to study their habits and mode of life, and especially the tracks which they made in sand or mud.

The King-crab, viewed from above, consists of three parts. The anterior shield or carapace is semi-circular in form, with two spines or projecting points at the angles, raised in the middle and sloping down to a smooth or moderately sharp edge in front. The eyes are set like windows in this shield. Two large ones at the sides, which are compound eyes consisting of numerous ocelli or little eyes, and two microscopic ones in front, at the base of a little spine, which are simple. The second or abdominal part is also in one piece, somewhat quadrate in form, with ridges and serratures at the sides armed with spines, and which may be said to simulate the separate joints into which the abdomen of an ordinary Crustacean is divided. The third part is a long tail spine, triangular in cross section, sharply pointed, and so jointed to the posterior end of the abdomen that it can be freely moved in any direction as a bayonet-like weapon of defence. When unable to escape from an enemy it is the habit of the creature to double itself up by bending the abdomen against the carapace, and erecting the sharp spine. Thus, with fixed bayonet it awaits attack, like the kneeling soldier in front of a square.

Below this upper shield, which is thin and papery in the young, somewhat horny in the adult, are the numerous limbs of the creature, with which we are at present most concerned.

Under the carapace are several pairs of jointed limbs differing in size and form. The two anterior are small and peculiarly formed claws, used apparently in manipulating the food. The four next are larger in size, and are walking feet, each furnished with two sharp points which form a pincer for holding. The last pair is much larger and stronger than any of the others, and armed not only with a pair of pincers, but with four blunt nail-like points. Under the abdomen are flat swimming feet, as they have been called, each composed of a broad plate notched and divided in the middle. When at rest these lie flat on each other, but they can be flapped back and forth at the will of the animal.

Let us now see what use the creature can make of these numerous and varied pedal appendages, and for distinctness' sake we shall call the anterior set thoracic and the posterior abdominal. When placed in shallow water on fine sand it walked slowly forward, and its tracks then consisted of a number of punctures on the sand in two lines. If, however, the water was very shallow or the sand very soft or inclined upward the two edges of the carapace touched the bottom, making a slight furrow at each side ; and if the tail was trailed on the bottom, this made a third or central furrow. When climbing a slope, or when placed at the edge of the water, it adopted another mode of locomotion, pushing with great force with its two posterior limbs, and thus moving forward by jerks. It then made four deep marks with the toes of each hind limb, and more or less interrupted marks with the edges of the carapace and the tail. In these circumstances the marks were almost exactly like those of some forms of the Protichnites of the Potsdam sandstone. When in sufficiently deep water and desirous to escape, it flapped its abdominal feet, and then swam or glided close to the bottom. In this case, when moving near the soft bottom, it produced a series of transverse ridges and furrows like small ripple marks, with a slight ridge in the middle,

and sometimes, when the edges of the carapace touched the bottom, with lateral furrows. In this way the animals were able to swim with some ease and rapidity, and on one occasion I observed an individual, confined in a tub of water, raise itself from the bottom and swim around the tub at the surface in search of a way of escape. Lastly, the young Limuli were fond of hiding themselves by burrowing in the sand. They did this by pushing the anterior rounded end of the carapace under the sand, and then vigorously shovelling out the material from below with their feet, so that they gradually sank under the surface, and the sand flowed in upon them till they were entirely covered. If carefully removed from the hollow they had made, this was found to be ovoid or hoof shaped in form and bilobed, not unlike the curious hollows (*Rusophycus Grenvillensis* of Billings) which I have supposed to be burrows of Trilobites.

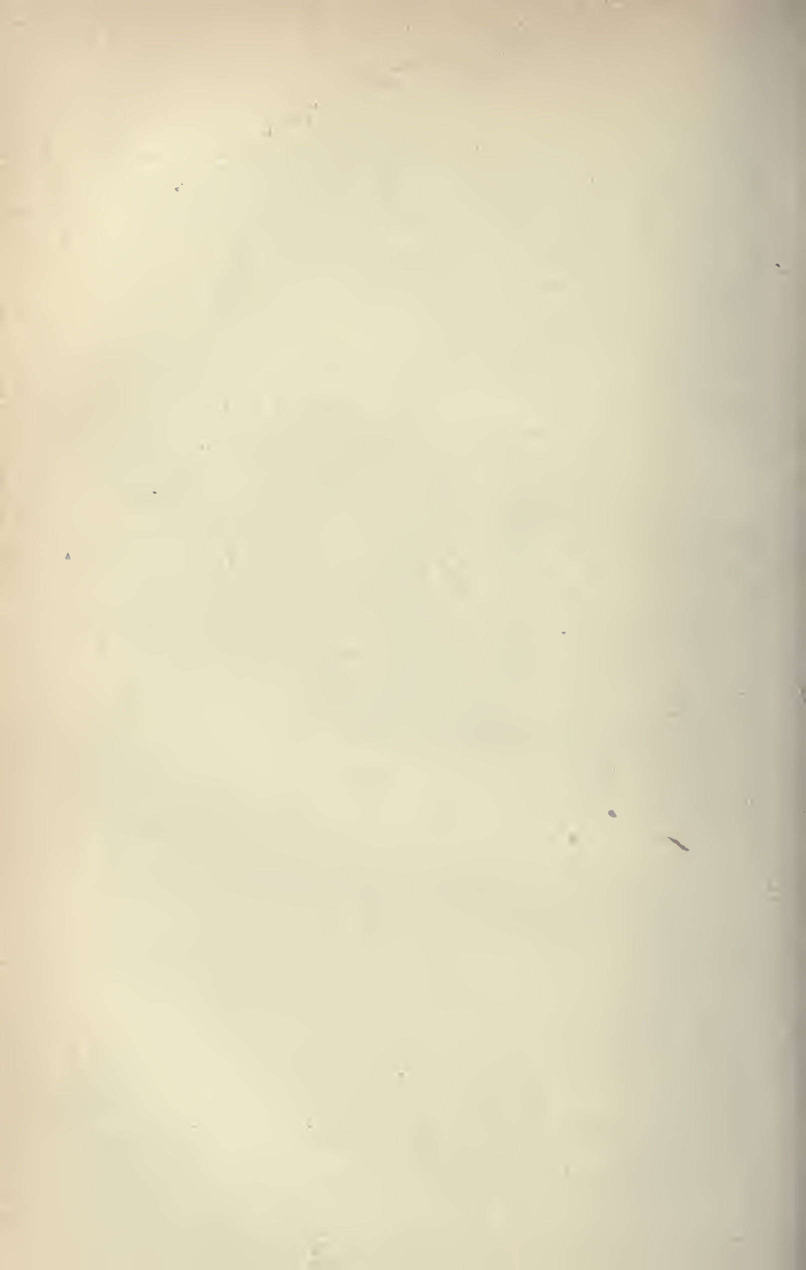
I thus found that the common King-crab could produce a considerable variety of tracks and burrows comparable with those which have been named Protichnites, Climactichnites, Bilobites, Cruziana, Rusichnites, etc. ; and that the kind of markings depended partly on the differences of gait in the animal, and partly on the circumstances in which it was placed ; so that different kinds of tracks do not always prove diversity in the animals producing them.

The interest of this investigation as applied to Limulus is increased by the fact that this creature is the near ally of Trilobites, Eurypterids and other Crustaceans which were abundant in the earlier geological ages, and whose footprints are probably among the most common we find on the rocks.

Lastly, on this part of the subject, it is to be observed that many other marine animals, both crustaceans and worms, make impressions resembling in general character those of Limulus. In addition to those already mentioned, Nathorst and Bureau have shown that various kinds of shrimps and lobster-like Crustaceans, when swimming rapidly by successive strokes of



RUSICHNITES GRENVILLENSIS, Billings—a "Bilobite."
Probably the Cast of a Crustacean burrow.



the tail, make double furrows with transverse ridges resembling those of Bilobites, and there are even some mollusks which by the undulations of the foot or the hook-like action of its anterior part, can make similar trails. A question arises here as to the value of such things as fossils. This depends on the fact that many creatures have left their marks on the rocks when still soft on the sea bottom, of which we have no other indications, and it also depends on our ability to understand the import of these unconscious hieroglyphics. They will certainly be of little use to us so long as we persist in regarding them as vegetable forms, and until we have very carefully studied all kinds of modern markings.[1] Nor does it seem of much use to assign to them specific names. The same trail often changes from one so-called species, or even genus, to another in tracing it along, and the same animal may in different circumstances make very different kinds of tracks. There will eventually, perhaps, arise some general kind of nomenclature for these markings under a separate sub-science of Ichnology or the doctrine of Footprints.

I have said nothing of true Algæ or seaweeds, of which there are many fossil species known to us by their forms, and also by the carbonaceous or pyritous matter, or discharge of colour from the matrix, which furnishes evidence of the presence of organic material; nor of the marks and trails left by seaweeds and land plants drifting in currents, some of which are very curious and fantastic; nor of those singular trails referred to the arms of cuttlefishes and the fins of fishes, or to sea jellies and starfishes. These might form materials for a treatise. My object here is merely to indicate the mode of dealing with such things, and the kind of information to be derived from them.

When we come to the consideration of actual footprints of

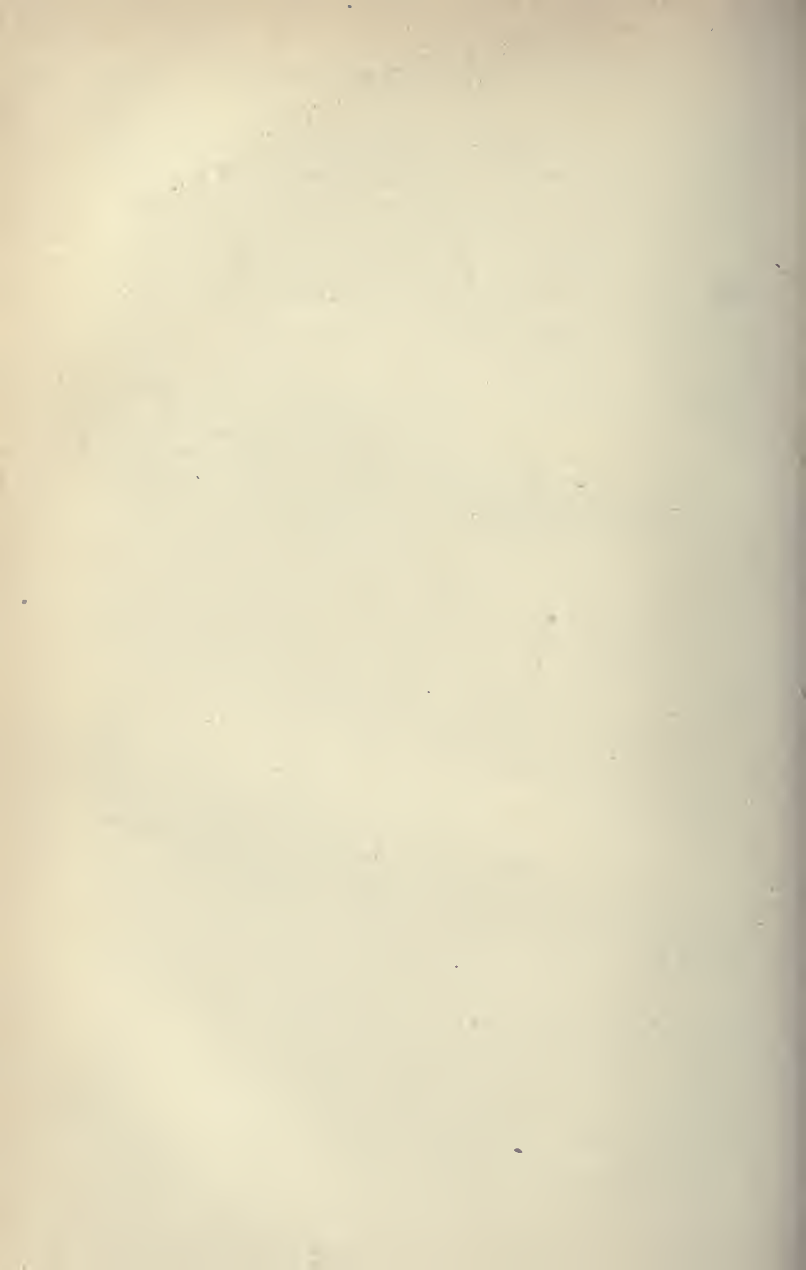
[1] Geologists are greatly indebted to Dr. Nathorst of Stockholm for his painstaking researches of this kind.

vertebrate animals having limbs, the information we can obtain is of a far more definite character. This has already been referred to in treating of the first Air-breathers in a previous chapter. One very curious example we may close with. It is that of the celebrated " bird tracks " of the sandstone quarries in the Trias of Connecticut and Massachusetts. These tracks, of immense size, as much as eighteen inches in length, and so arranged as to indicate the stride of a long-legged biped, were naturally referred to gigantic birds, allied to modern waders. But when it was found that some of them showed a central furrow indicating a long tail trailing behind, this conclusion was shaken, and when in tracing them along, places were found where the animal had sat down on its haunches and the end of its tail, and had brought down to the ground a pair of small fore feet with four or five fingers, it was discovered that we had to deal with biped reptiles; and when the tracks were correlated with the bones of the extinct reptiles known as Dinosaurs, we found ourselves in the presence of a group of the most strange and portentous reptilian forms that the earth has ever known. Marsh has been enabled, by nearly perfect skeletons of some allied reptilian bipeds found in the West, to reproduce them in their exact forms and proportions, so that we can realize in imagination their aspect, their gait, and their gigantic proportions. Examples of this putting together of footprints and osseous remains of vertebrate animals are not rare in the history of geology, and show us how the monsters of the ancient world, equally with their human successors, could leave "footprints on the sands of time."

The Dinosaurs which have left their footprints on the sandstones of Connecticut and Massachusetts are, however, greatly more numerous than those known to us by osseous remains. Thus footprints have the further use of filling up the imperfections of our geological record, or at least of pointing out gaps which but for them we might not have suspected. The re-

markable inferences of Matthew already referred to, respecting cuttlefishes in the Cambrian period, constitute a case in point. Footprints of Batrachians in the Carboniferous rocks were known before their bones. The strange hand-like tracks in the Trias were known before we knew the Labyrinthodon that produced them. We are still ignorant of the animals whose tracks in the old Potsdam sandstones we name Protichnites.

REFERENCES :—On Rusichnites (a form of Bilobite), *Canadian Naturalist*, 1864. On Footprints of Limulus compared with Protichnites, etc. *Ibid.* On Footprints and Impressions of Aquatic Animals and Imitative Markings, *Amer. Journal of Science*, 1873. On Burrows and Tracks of Invertebrate Animals, *Quarterly Journal* of *Geological Society*, 1890. On Footprints of Carboniferous Batrachians. "Acadian Geology," "Air-breathers of the Coal Period," etc.



PRE-DETERMINATION IN NATURE.

DEDICATED TO THE MEMORY OF

ELKANAH BILLINGS,

FIRST PALÆONTOLOGIST OF

THE GEOLOGICAL SURVEY OF CANADA,

WHO LAID THE FOUNDATIONS OF OUR KNOWLEDGE

OF THE INVERTEBRATE FOSSILS OF CANADA.

Fixity of Laws and Properties of Energy and Matter —Permanence of Continents and Oceans — The Permanent and the Changeable – Permanence of Animal and Vegetable Forms and Structures — Principles of Construction in the Parts of Trilobites—In the Skeletons of Sponges — In Early Vertebrates — In Plants — Laws of Fixity and Diversity





RESTORATION OF PROTOSPONGIA TETRANEMA.—Quebec group; Siluru-Cambrian, Little Metis (p. 335).

CHAPTER XII.

PRE-DETERMINATION IN NATURE.

THE natural prejudice of persons not acquainted with geology is that in the world all things continue as they were from the beginning. But a little observation and experience dispels this delusion, and perhaps replaces it with an opposite error. When our minds have been familiarized with the continuous processes by which vaporous nebulæ may be differentiated into distinct planets, and these may be slowly cooled from an incandescent state till their surfaces become resolved into areas of land and water; and still more, when we contemplate the grand procession of forms of life from the earliest animals and plants to man and his contemporaries, we become converts to the doctrine that all things are in a perpetual flux, and that every succeeding day sees them different from what they were the day before. In this state of mind the scientific student is apt to overlook the fact that there are many things which remain the same through all the ages, or which, once settled, admit of no change. I do not here refer to those fundamental properties of matter and forces and laws of nature which form the basis of uniformitarianism in geology, but to determinations and arrangements which might easily have been quite different from what they are, but which, once settled, seem to remain for ever.

We have already considered the great fact that the nuclei and ribs of the continental masses were laid down as foundations in the earliest periods, and have been built upon by determi-

nate additions, more especially upon their edges and their hollows, so that while there has been a constant process of removal of material from the higher parts of the land, and deposition in the sea, and while there have been periodical elevations and subsidences, the great areas of land and water have remained substantially the same, and the main lines of elevation and folding have conformed to the directions originally fixed. Thus, in regard to the dry land itself, there has been fixity, on the one hand, and mutation on the other, of a most paradoxical aspect, till we understand something of the great law of constant change united with perennial fixity in nature. From want of attention to this, the permanence of continents is still a debated question, and it is difficult for many to understand how the frequent dips of the continental plateaus and margins under the sea, and their re-elevation, often along with portions of the shallower sea bottom, can be consistent with a general permanence of the position of the continents and of the corresponding ocean abysses; yet, when this is properly understood, it becomes plain that the union of fixity with changes of level has been a main cause of the continuity and changes of organic beings. Only the submergence of inland plateaus under shallow and warm waters could have given scope for the introduction of new marine faunas, and only re-elevation could have permitted the greatest extension of plants and animals of the land. Thus, the continuity of life with continual advance has depended on the permanent existence of continental and oceanic areas; and the continents that remain to us with all their diversity of elevation and outline, their varied productions, both mineral and organic, and their life, which is a select remainder of all that went before, have been produced and furnished by a succession of changes, modified by the most conservative retention of general arrangements and forms.

It is evident, however, that it is not merely permanence we

have to deal with here, but permanence of position along with change of elevation; and this modified by the fact that there have always been mountain ridges, internal plateaus, and marginal areas affected in various ways by the vertical movement of the land. Further, the elevation and subsidence of the land have not always been uniform, but often differential, while every movement has tended to produce modifications of ocean currents and of atmospheric conditions. The whole subject, more especially in its relations to life, thus becomes very complicated, and it is perhaps in consequence of partial and imperfect views on these points that so much diversity of opinion has arisen. For example, it is evident that we can gain nothing by adding to the continents those submerged margins delineated by Murray in the *Challenger* reports, and which have in periods of continental elevation themselves formed portions of the land. Nor do we establish a case in favour of perished oceanic continents by the argument that they are needed to furnish the materials of marginal mountains which are due to the continuous sweeping of arctic material to the south by currents, as we see in the coast of North America to-day. Nor do we invalidate the permanence of the continents by the bridges of land, islands, and shallow water at various times thrown across the Atlantic. The distribution of Cambrian Trilobites, as illustrated by Matthew,[1] seems to show a bridge of this kind in the north in very early times, and similar evidence is furnished by the animals and plants of the Devonian and Carboniferous, and by the sea animals and plants of the later Tertiary and modern. Gardener has postulated a southern bridge in the region of the West Indies for the migrations of plants, and Gregory has adduced the evidence of those conservative and slow-moving creatures, the sea urchins, in favour of similar connection in the West Indian region at two distinct periods of time (the Lower Cretaceous and the Miocene Tertiary). But

[1] Transactions Royal Society of Canada, 1892.

bridges do not involve want of permanence in their termini. Because an engineer has bridged the Firth of Forth, it does not follow that the banks of this inlet did not exist before the bridge was built; and if the bridge were to perish, the evidence that trains had once passed that way would not justify the belief that the bed of the Firth had been dry land, and the areas north and south of it depressed. The more we consider this question the more we see that the permanence, growth and sculpture of the continents are parts of a great continuous and far-reaching plan. This view is strengthened rather than otherwise, when we consider the probable manner in which the enormous weight of the continents is sustained above the waters. We may attribute this, on the one hand, to rigidity and lateral arching and compression, or, on the other, to what may be termed flotation of the lighter parts of the crust; and there seems to be little doubt that both of these principles have been employed in constructing the "pillars which support the earth." It is evident, however, that an arch thrown over the internal abyss of the earth, or a portion of its crust so lightened as to be pressed upward by its heavier surroundings, must, when once established, have become a permanent feature of the earth's foundations, not to be disturbed without calamitous consequences to its inhabitants.

It is the part of the philosophical naturalist to bring together these apparent contrarieties of mutation and permanence; both of which are included, each in its proper place, in the great plan of nature. It is therefore my purpose in the present chapter to direct attention to some of the terminal points or fixed arrangements that we meet with in the course of the geological history, and even in its earlier parts, and more particularly in reference to the organic world. This, which is in itself constantly changing, has been placed under necessity to adhere to certain determinations fixed of old, and which regulate its forms and possibilities down to our own time.

The argument, as we have seen in a previous chapter, for the animal nature of Eozoon depends on our assuming certain parts of this fixity. We suppose that then as now calcium carbonate had been selected as the material for the skeletons of such creatures ; that then, as now, minute tubuli and large canals were necessary to enable the soft animal matter to permeate and pass through the skeleton, and that the protoplasmic animal matter of these far back geological periods had the same vital properties of contraction and extension, digestion, etc., that it has to-day. Could any one prove that these determinations of vital and other forces had not been established, or that living protoplasmic matter, with all its wonderful properties, had not been constructed in the Laurentian period, the existence of this ancient animal would be impossible. Yet how much is implied in all this, and though nothing is more unstable chemically or vitally than protoplasm, if it were introduced in the Laurentian, it has continued practically unchanged up to the present time.

If we pass on to the undoubted and varied life of the Cambrian period, we shall find that multitudes of things which might have been otherwise were already settled in a way that has required no change.

In the oldest Trilobites the whole of the mechanical conditions of an external articulated skeleton had been finally settled. The material chitinous or partly calcareous, its microscopic structure, fitted to combine lightness and strength with facility for rapid growth, the subdivision of its several rings, so as to form a protective armour and a mobile skeleton, the arrangement of its spines for defence without interfering with locomotion, the contrivance of hinge joints arranged in different planes in the limbs,—all these were already in full perfection, and just as they are found to-day in the skeleton of a king-crab or any other Crustacean. They have, it is true, been modified into a vast number of subordinate forms and uses,

but the general principles and main structures all stand. I was much struck with this recently in studying a remarkable specimen now in the National Museum at Washington. It is a large species of Asaphus; the same genus which gave to the late Mr. Billings the limbs of a Trilobite, the first ever described; but in the Washington specimen they are remarkably perfect. Each limb presents a series of joints resembling those of the tarsus of an insect, each joint being of conical form with the narrow proximal end articulated to the enlarged distal end of the previous one, so as to give great facility of movement and accommodation for delicate muscular bands. This tells us of muscular fibre and tendon fitted for flexing and extending these numerous joints, of motor nerves to work that marvellous contractile power of the striated muscle, whose mode of action is still an insoluble mystery, yet one practically solved in the remote Cambrian age for the benefit of these humble inhabitants of the sea. If we could imagine that the inventive power to perfect such machinery was present in the brains of these old Crustaceans or Arachnidans, we might wish that some of them had survived to instruct us in matters which baffle our research.

It is long since the compound eyes of these Trilobites, as illustrated by Burmeister, gave Buckland the opportunity to infer that the laws of light and of vision were the same from the first as now. But what does this imply? Not only that the light of the sun penetrating to the depths of the Cambrian sea, was regulated by the same laws as to-day, but that a series of cameras was perfected to receive the light as reflected from objects, to picture the appearance of these objects on a retinal screen as sensitive as the film of the photographer, and thereby to produce true perceptions of vision in the sensorium of these ancient animals. I have before me a fragment of the eye of a Trilobite (*Phacops*), in which may be seen the little radiating tubes provided for the several ocelli of the compound eye, just

as we see in the modern Limulus; and each of these ocelli must have been a perfect photographic camera, and more than this, since absolutely automatic, and probably having the power to represent colour as well as light and shade. We know also, from the recent experiments of an Austrian physiologist on the eyes of insects, that such compound eyes are so constructed as to present a single picture, just as we can see the whole landscape in looking through the many little panes of a cottage window. In our own time the king-crab and lobster no doubt see just as their predecessors did millions of years ago, and with precisely similar instruments.

But the eyes of the modern Crustaceans have to compete with eyes of a dissimilar type, constructed on the same general optical principles, but quite different in detail. These are the simple or single eyes of the cuttlefishes and the true fishes. The same rivalry existed in the oldest seas, when the competition of Crustaceans and cuttles was just as keen as now. Though the eyes of the latter have not been preserved, or at least have not yet been found, we have a right to infer that the cuttles of the Cambrian and Silurian seas must have been able to see as well as their Crustacean foes and competitors. If so, the other type of eye must have been perfected for aquatic vision as early as the compound type. In any case we know that a little later, in the Carboniferous period, we have evidence that the eyes of fishes conformed to those of their modern successors. I have myself described [1] a carboniferous fish (*Palæoniscus*) from the bituminous shales of Albert County, New Brunswick, in which the hard globular lens of the eye had been sufficiently firm and durable to retain its form, and to be replaced by calcite, showing even that like the lens of the eye of a modern fish it had been constructed of concentric laminæ. In the Carboniferous period also, both types of eye, the compound and the single, experienced the further modifications

[1] *Canadian Naturalist.*

necessary to fit them for vision in air, the compound eye in insects, the simple eye in Batrachians.[1] The original photographic cameras, strange though this may appear to us, were intended for use under water; but at a very early time they were adapted to work in air.

But we must bear in mind that this early solving of advanced problems in mechanics, optics and physiology was in favour of Crustaceans and cuttles, which were lords of creation in their time. There were in those early days humbler creatures whose structures also present wonderful contrivances.

I have already referred, in the chapter on imperfection of the geological record, to the fossil sponges which have been found in so great number and perfection in some of the oldest rocks of Canada, and which have for the first time enabled us to appreciate the forms and structures of the wonderful silicious sponges which preceded those with which the dredgings of the *Challenger* have made us familiar in the modern seas. Humble sarcodous animals, without distinct muscular or nervous system or external senses, the sponges have at least to live and grow, and to that end they must already, in the dawn of life on our planet,[2] have perfected those arrangements of ciliated cells in chambers and canals which the microscope shows us driving currents of water through the modern sponges, and thereby bringing to them the materials of food and means of respiration. It is true we know as little as the sponges themselves of the *modus operandi* of those perpetually waving threads which we call cilia or flagella, yet they must have existed with all their powers even before the Cambrian period.[3]

[1] See *ante*, chapter on Air-breathers.

[2] I have found spicules of sponges in the chert nodules from the Huronian limestones of Canada.

[3] Many species of hexaclinelled sponges have have been described from the upper Cambrian or lower Cambro-Silurian of Canada. See paper by the author in the Transactions of the Royal Society of Canada, 1889.



A GIANT NET-SPONGE.—*Palæosaccus Dawsoni*, Hinde.
From the Quebec group (Ordovician), Little Metis, Canada.
Reduced to $\frac{3}{7}$ the diameter.
(From the *Geological Magazine*, 1803.)



The sponge, in order to support its delicate protoplasmic structures, must have a skeleton. In modern times we find these creatures depositing corneous or horny fibres, as in the common washing sponges, or forming complex and beautiful structures of needles, or threads of silica or calcite, and they seem from the first to have been able to avail themselves of all these different materials. The oldest species that we know had silicious or calcareous skeletons, though some of them must also have had a certain amount, at least, of the ordinary spongy or corneous fibres. But the most astonishing feature in what remains of their skeletons, flattened out as they are on the surfaces of dark slaty rock, is the manner in which they worked up so refractory a material as silica into fibres like spun glass rods and crosses, and built these up into beautiful basket-like forms, globular, cylindrical or conical. It was necessary that they should fix themselves on the soft muddy bottoms on which they grew, and to this end they produced slender silicious fibres or anchoring rods, which, fine though they were, had the form of hollow tubes. Sometimes a single rod sufficed, but in this case it had a crosslike anchor affixed to its lower end, to give it stability. Sometimes there were several simple rods, and then they were skilfully braced by spreading them apart at the ends, and by flattening their extremities into blades. Sometimes four rods joined in a loop at the end gave the required support. Some larger species wound together many threads like a wire rope, and even added to this flanges like the thread of a screw, anticipating the principle of the modern screw pile.

The body of the sponge must be hollow within, and must have a large aperture or opening for the discharge of water, and smaller pores for its admission. Various general forms were adopted for this. Some were globular, or oval, or pear-shaped; others cylindrical, concave, or mitre-shaped. To give form and strength to these shapes there were sometimes vertical and

transverse rods soldered together. In other cases there were four-rayed or six-rayed needles of silica, with their points attached so as to form a beautiful lattice-work, with its meshes either square or lozenge-shaped. For protection sharp needles were arranged like *chevaux de frize* at the sides and apertures, and these last were sometimes covered with a hood or grating of needles, to exclude intruders from the interior cavity. Other species, however, like some in the modern seas, seemed to despise these niceties, and contented themselves with long straight needles placed in bundles, or radiating from a centre, and thus supporting and protecting their soft and sensitive protoplasm.

Curiously enough, these old sponges did not avail themselves of the natural cystallization of silica, which, left to itself, would have formed six-rayed stars, with the rays at angles of sixty degrees, or six-sided plates, rods, or pyramids. They adopted another and peculiar form of the mineral, known as colloidal silica, and being thus relieved from any need to be guided by its crystalline form, treated it as we do glass, and shaped it into cylindrical tubes, round needles and stars or crosses, with the rays at right angles to each other.

The sponges whose skeletons are thus constructed, and which anticipated so many mechanical contrivances long afterwards devised by man, belonged to a group of silicious sponges (*Hexaclinellidæ*) which is still extant, and represented by many rare and beautiful species of the deep sea, which are the ornaments of our museums, and of which the beautiful *Eupleectella* or Venus flower-basket, from the Philippine Islands, and the glass-rope sponge (*Hyalonema*), from Japan, are examples. But contemporary with these there was another group (*Lithistidæ*), constructing skeletons of carbonate of lime, and which preferred, instead of the regular mechanical structures of the others, a kind of rustic work, made up of irregular fibres, very beautiful and strong, but as a matter of pattern and taste standing quite by itself. If there were any sponges with

altogether soft and spongy skeletons in these old times, their remains do not seem to have been preserved.

Here, it will be observed, are a great variety of vital and mechanical contrivances devised in the very early history of the earth, settled for all time, and handed down without improvement, and with little change, to our later day. They are indeed vastly more wonderful than the above general account can show; for to go into the details of structure of any one of the species would develop a multitude of minor complexities and niceties which no one not specially a student of these animals could appreciate.

These are not solitary cases. The student of fossils meets with them at every turn; and if he possesses the taste and imagination of a true naturalist, cannot fail to be impressed with them.

To turn to a later but very ancient period, what can be more astonishing than those first air-breathing vertebrates of the Coal formation referred to in a previous chapter, with all their special arrangements for an aërial habitat? I have mentioned their footprints, and when we see the quarrymen split open a slab of sandstone and expose a series of great plantigrade tracks, not unlike those of a human foot, with the five toes well developed, we are almost as much astonished as Crusoe was when he saw the footprints on the sand. Crusoe inferred the presence of another man in his island; we infer the earliest appearance of an air-breathing vertebrate and the pre-human determination of the form and number of parts of the human foot and hand, to appear in the world long ages afterward. We see also that already that decimal system of notation which we have founded on the counting of our ten fingers was settled in the framework of most unmathematical Batrachians. It has approved itself ever since as the typical and most perfect number of parts for such organs.

If sceptically inclined, we may ask, Why five rather than

four or six? In the case of man we see that individuals who have lost one finger have the use of the hand impaired, while the few who happen to have six do not seem to be the better. How it was with the old Batrachians we do not know; but it is certain that if we could have amputated the claw-bearing little toe of *Sauropus unguifer*, or the reflexed little toe of *Cheirotherium*, we should have much injured their locomotive power.

The vegetable kingdom is full of similar examples of the early settlement of great questions. Perhaps nothing is more marvellous than the power of the green cells of the leaf as workers of those complex and inimitable chemical changes whereby out of the water, carbon dioxide and ammonia of the soil and the atmosphere, the living vegetable cell, with the aid of solar energy, elaborates all the varied organic compounds produced by the vegetable kingdom. Yet this seems all to have been settled and perfected in the old Silurian period, long before any kind of plant now living was on the earth. Perhaps in some form it existed even in the Laurentian age, and was instrumental in laying up its great beds of carbon. So all that is essential in plant reproduction, whether in that simpler form in which a one-celled spore is the reproductive organ, or in that more complex form in which an embryo plant is formed in the seed, with a store of nourishment laid up for its sustenance.

These arrangements were obviously as perfect in the great club mosses and pines of the Devonian and Carboniferous as they have ever been since, and we have specimens so preserved as to show their minute parts just as well as in recent plants. The microscope also shows us that the contrivances for thickening and strengthening the woody fibres and trunk of the stem by bars or interrupted linings of ligneous matter, so as to give strength and at the same time permit transudation of sap, were all perfected, down to their minutest details, in the oldest land plants. It is true that flowers with gay petals and some of the

more complicated kinds of fruit are later inventions, but the additions in these consist mainly of accessories. The essentials of vegetable reproduction were as well provided for from the first.

The same principle applies to many of the leading forms and types of life, considered as genera or species. While some of these are of recent introduction, others have continued almost unchanged from the remotest ages. Such creatures as the Lingulæ, some of the Crustaceans and of the Mollusks, the Polyzoa and some Corals have remained with scarcely any change throughout geological time, while others have disappeared, and have been replaced by new types.

We began this chapter with a consideration of the permanence of continental areas, and may close with a reference to the same great fact in connection with the continuity of life. Whether with some we attach more importance to the support of the continents by lateral pressure and rigidity, or with others to what may be termed flotation, by virtue of their less density, as compared with that of the lower parts of the earth ; there can be little doubt that both principles have been applied, and that both admit of some vertical movement. Thus the stability of the continents is one of position rather than height, and their internal plateaus as well as their partially submerged marginal slopes have undergone great and unequal elevations and depressions, causing most important geographical changes. Among these are the formation of connecting bridges of shoals, islands, or low land, connecting the continental masses at different periods, and permitting migrations of shallow-water animals and even of denizens of the land. The facts adduced in previous pages are sufficient to show connections across the north of the Atlantic at intervals reaching from the Cambrian to the Modern.

The conclusion of the whole matter is that there is a fixity and unchangeableness in determinations and arrangements of

force just as much as in natural laws ; and that while God has made everything beautiful in its time He has also made everything beautiful and useful in some sense for all time. With all this, while the great principles and modes of operation remain unchanged, there is ample scope for development, modification and adaptation to new ends, without deviation from essential properties and characters. It is a wise and thoughtful philosophy which can distinguish what is fixed and unchangeable from that which is fluctuating and capable of development. Until this distinction is fully understood, we may expect one-sided views and faulty generalizations in our attempts to understand nature.

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THE GREAT ICE AGE.

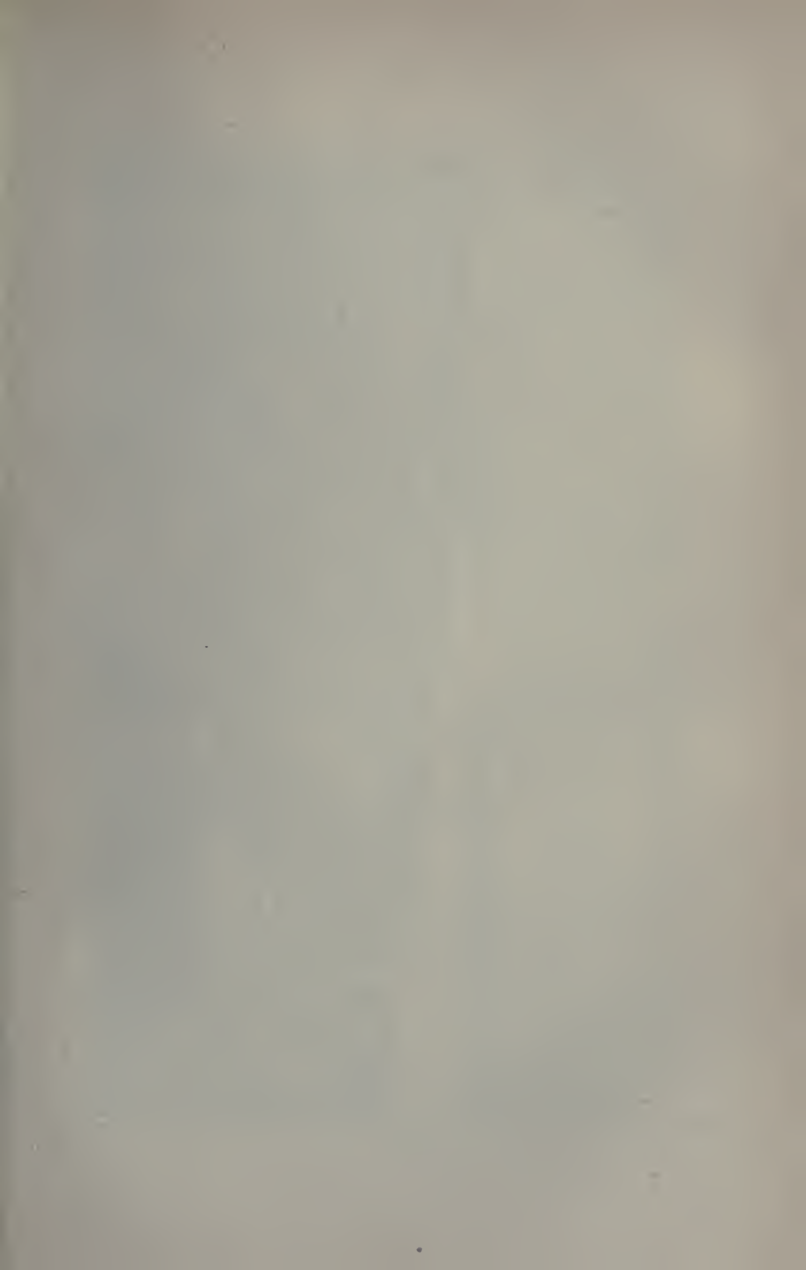
DEDICATED TO THE MEMORY OF

MY LATE FRIEND

DAVID MILNE HOME, LL.D., F.R.S.E., ETC.,

AN EMINENT AND JUDICIOUS ADVOCATE OF SOUND AND MODERATE VIEWS RESPECTING THE GLACIAL AGE.

Exaggerated Ideas—The St. Lawrence Valley—Modern Ice Action in the St. Lawrence—Coast Ice—The Icebergs of Belle-Isle—Mt. Blanc and its Glaciers—Effects of Glaciers — Possible Extension of Glaciers—Facts of Glaciation in Canada.—Cordilleran Glacier, Laurentide Glacier, Appalachian Glacier—Submerged Valleys and Plains—Double Submergence and Intermediate Partial Elevation—Interglacial Periods—Questions as to Alternate Glaciation of Northern and Southern Hemispheres





MODERN BOULDER BEACH.—Little Metis, St. Lawrence Estuary.

(From a Photograph.)

Showing the manner in which travelled boulders are piled up against the beach by the floating ice of the

CHAPTER XIII.

THE GREAT ICE AGE.

SCIENTIFIC superstitions, understanding by this name the reception of hypotheses of prominent men, and using these as fetishes to be worshipped and to be employed in miraculous works, are scarcely less common in our time than superstitions of another kind were in darker ages. One of these which has been dominant for a long time in geology, and has scarcely yet run its course, is that of the Great Ice Age, with its accompaniments of Continental Glaciers and Polar Ice Cap. The cause of this it is not difficult to discern. The covering of till, gravel and travelled boulders which encumbers the surface of the northern hemisphere from the Arctic regions more than half way to the equator, had long been a puzzle to geologists, and this was increased rather than diminished when the doctrine of appeal to recent causes on the principle of uniformity became current. It was seen that it was necessary to invoke the action of ice in some form to account for these deposits, and it was at the same time perceived that there was much evidence to prove that between the warm climate of the early Tertiary and the more subdued mildness of the modern time there had intervened a period of unusual and extreme cold. In this state of affairs attention was attracted to the Alpine glaciers. Their movement, their erosion of surfaces, their heaping up of moraines bearing some resemblance to the widely extended boulder deposits, their former greater extension, as indicated

by old moraines at lower levels than those in process of formation, were noted. Here was a modern cause capable of explaining all the phenomena. Men's minds were taken by storm, and as always happens in the case of new and important discoveries, the agency of glaciers was pushed at once far beyond the possibilities of their action under any known physical or climatal laws. This exaggerated idea of the action of land ice in the form of glaciers is not yet exploded, more especially in the United States, where official sanction has been given to it by the Geological Survey, and where it has been introduced even into school and college text-books. It affords also a telling bit of scientific sensationalism, which can scarcely be resisted by a certain class of popular writers. America has also afforded greater facilities for extreme theories of this kind, owing to the wide and uninterrupted distribution of glacial deposits, and the more simple and less broken character of its great internal plateau, while the influence of great leading minds, like those of the elder Agassiz and of Dana, naturally held sway over the younger geologists. Fortunately Canada, which possesses the larger and more northern half of the North American continent; though numerically inferior, and therefore overborne in the discussion, has, in the main, remained stedfast to facts rather than to specious theories, and has been confirmed in this position by the clearer testimony of nature in a region where many of the features of the glacial age still persist.[1]

The writer of these pages has, ever since the publication of the first edition of his "Acadian Geology,"[2] steadily resisted the more extreme views of glaciation, and has opposed the southward progress of the great continental glacier. Though, figuratively speaking, overborne and pressed back in the

[1] I may refer here to the recent researches of Dr. G. M. Dawson, Mr. R. Chalmers, Mr. McConnell and Dr. Ells.

[2] 1855.

course of its extension, he has now, like those primitive men who are imagined in the post-glacial age to have followed up the retreat of the ice, the pleasure of seeing the once formidable continental glacier broken up into great local glaciers on the mountain ranges separated by intervening areas of submergence.

The questions relating to this subject are too numerous and varied for treatment here. The question of the causes of the great lowering of temperature in the glacial age I shall leave for consideration in the next chapter, and merely state here that I believe changes of distribution of sea and land and of ocean currents are sufficient to account for all the refrigeration of which there is good evidence. I content myself with a comparison of the glacial phenomena of Mont Blanc and of the Gulf of St. Lawrence from my own observation,[1] and some general deductions as to glacier possibilities.

A scientific voyager carries with him a species of questioning peculiar to himself. Not content with vacantly gazing at the sea, scrutinizing his fellow passengers, noting the changes of the weather and the length of the day's run, he recognises in the sea one of the great features of the earth, and questions it daily as to its present and its past. The present features of the sea include much of surpassing interest, but the questions which relate to its origin and early history are still more attractive. Some of these questions are likely to interest a voyager from Canada entering the Atlantic by one of its greatest tributaries, the St. Lawrence.

In doing so, we approach the ocean not at a right angle, but along a line only slightly inclined to its western side, and we find ourselves in a broad estuary or trough, having on its north-western side rugged hills of old crystalline rocks, the Laurentian, ridged up in great folds or earth waves parallel to the river. On the south-east or right-hand side we have

[1] Published in 1867.

a lower barrier of earth waves composed of sedimentary rocks somewhat later in date, but still geologically very ancient. We are thus introduced to a remarkable feature of the west side of the North Atlantic, namely, that its border is made up of very old rocks folded into mountain ridges thrown up at an ancient period, and approximately parallel to the coast. The Lower St. Lawrence occupies a furrow between two of these ridges.

Here, however, a more modern feature attracts our attention. The sides of the bounding hills are cut in a succession of terraces, rising one above another from the level of the sea to a height of 500 feet or more, capped with long ranges of the white houses and barns of the Canadian habitants, and furnishing level lines for the "concession roads" which run along the coast. These terraces are really old sea margins indicating the stages of the elevation of the land out of the sea immediately before the modern period. On these terraces, and in the clays and sands which form the plateaus extending in some places in front of them, are sea shells of the same kinds with those now living in the Gulf of St. Lawrence, and occasionally we find bones of whales which have been stranded on the old beaches.

These terraces are, of course, indications of change of level in very modern times. They show that in what we call the Pleistocene age the land was lower than at present, and we shall find that in the Lower St. Lawrence there is evidence of a depression extending to over 1,000 feet, carrying the sea far up the valley, so that sea shells are found in the clays as far up as Kingston and Ottawa, and stranded skeletons of whales as far west as Smith's Falls, in Ontario.

If we examine the shores more minutely, we shall find all along the south coast a belt of boulders which are often as much as eight to ten feet in diameter, and consist largely of rocks found only in the hills of the northern coast, more

than thirty miles distant, from which they must have been drifted to their present position. This boulder belt, which extends from the lowest tide mark about fifty feet or more upward, is sometimes piled in ridges and sometimes flattened out into a rude pavement. It is a product of the modern field ice, which, attaining a great thickness in winter, has boulders frozen into its bottom, and floating up and down with the tide, deposits these on the shore. At Little Metis, two hundred miles below Quebec, where I have a summer residence, I have from year to year cleared a passage through the boulder belt for bathing and for launching boats, and nearly every spring I find that boulders have been thrown into the cleared space by the ice, while one can notice from year to year differences in the position of very large boulders.

If we pass inland from the shore belt of boulders, we shall find similar appearances on the inland terraces at various heights, up to at least 400 feet. These are inland boulder belts belonging to old shores now elevated. Like the modern boulder belt these inland belts and patches consist partly of Laurentian rocks from the North Shore, partly of sandstones and conglomerates in place near to their present sites. In some places the stones are smaller than those of the present beach, in other places of gigantic size. These boulders lie not only on the bare rock striated in places with ice grooves pointing to the north-north-east; but on the old till or boulder clay, which also abounds with boulders, and which is more ancient than the superficial boulder drift. Locally we find here and there masses of fossiliferous limestone which must have been derived from the high ground to the south of the St. Lawrence, and which have been borne northward either by drift ice or by local glaciers.

If now we study the polished and scored surfaces of rocks in the St. Lawrence valley and the bounding hills, we shall find that while the former testify to a great movement of

ice and boulders up the river from the north-east, the latter show evident signs of the movement of locial glaciers down the valleys of the Laurentide hills to the south, and on the continuation of the Appalachians south of the river similar evidence of the movement of land ice to the north. Thus we have evidence of the combined action of local glaciers and floating ice. To add to all this, we can find on the flat tops of the hard sandstone boulders on the beach the scratches made by the ice of last winter, often in the same north-easterly direction with those of the Pleistocene time.

In addition to the ice formed in winter in the St. Lawrence itself, the snow-clad hills of Greenland send down to the sea great glaciers, which in the bays and fiords of that inhospitable region form at their extremities huge cliffs of everlasting ice, and annually "calve," as the seamen say, or give off a great progeny of ice islands, which, slowly drifted to the southward by the arctic current, pass along the American coast, diffusing a cold and bleak atmosphere, until they melt in the warm waters of the Gulf Stream. Many of these bergs enter the Straits of Belle-Isle, for the Arctic current clings closely to the coast, and a part of it seems to be deflected into the Gulf of St. Lawrence through this passage, carrying with it many large bergs. The voyager passing through this strait in clear weather may see numbers of these ice islands glistening in snowy whiteness, or showing deep green cliffs and pinnacles—sometimes with layers of earthy matter and stones, or dotted with numerous sea birds, which rest upon them when gorged with the food afforded by shoals of fish and others marine animals which haunt these cold seas. In early summer the bergs are massive in form, often with flat tops, but as the summer advances they become eroded by the sun and warm winds, till they present the most grotesque forms of rude towers and spires rising from broad foundations little elevated above the water.

Mr. Vaughan, late superintendent of the Lighthouse at Belle-Isle, has kept a register of icebergs for several years. He states that for ten which enter the straits, fifty drift to the southward, and that most of those which enter pass inward on the north side of the island, drift toward the western end of the straits, and then pass out on the south side of the island, so that the straits seem to be merely a sort of eddy in the course of the bergs. The number in the straits varies much in different seasons of the year. The greatest number are seen in spring, especially in May and June; and toward autumn and in the winter very few remain. Those which remain until autumn are reduced to mere skeletons; but if they survive until winter, they again grow in dimensions, owing to the accumulations upon them of snow and new ice. Those that we saw early in July were large and massive in their proportions. The few that remained when we returned in September were smaller in size, and cut into fantastic and toppling pinnacles. Vaughan records that on the 30th of May, 1858, he counted in the Straits of Belle-Isle 496 bergs, the least of them sixty feet in height, some of them half a mile long and 200 feet high. Only one-eighth of the volume of floating ice appears above water, and many of these great bergs may thus touch the ground in a depth of thirty fathoms or more, so that if we imagine four hundred of them moving up and down under the influence of the current, oscillating slowly with the motion of the sea, and grinding on the rocks and stone-covered bottom at all depths from the centre of the channel, we may form some conception of the effects of these huge polishers of the sea floor.

Of the bergs which pass outside of the straits, many ground on the banks off Belle-Isle. Vaughan has seen a hundred large bergs aground at one time on the banks, and they ground on various parts of the banks of Newfoundland, and all along the coast of that island. As they are borne by the deep-seated cold current, and are scarcely at all affected by the wind, they

move somewhat uniformly in a direction from north-east to south-west, and when they touch the bottom, the striation or grooving which they produce must be in that direction.

In passing through the straits in July, I have seen great numbers of bergs, some low and flat-topped, with perpendicular sides, others convex or roof-shaped, like great tents pitched on the sea; others rounded in outline or rising into towers and pinnacles. Most of them were of a pure dead white, like loaf sugar, shaded with pale bluish green in the great rents and recent fractures. One of them seemed as if it had grounded and then overturned, presenting a flat and scored surface covered with sand and earthy matter.

At present we wish to regard the icebergs of Belle-Isle in their character of geological agents. Viewed in this aspect, they are in the first place parts of the cosmical arrangements for equalizing temperature, and for dispersing the great accumulations of ice in the Arctic regions, which might otherwise unsettle the climatic and even the static equilibrium of our globe, as they are believed by some imaginative physicists and geologists to have done in the so-called glacial period. If the ice islands in the Atlantic, like lumps of ice in a pitcher of water, chill our climate in spring, they are at the same time agents in preventing a still more serious secular chilling which might result from the growth without limit of the Arctic snow and ice. They are also constantly employed in wearing down the Arctic land, and aided by the great northern current from Davis's Straits, in scattering stones, boulders and sand over the banks along the American coast. Incidentally to this work, they smooth and level the higher parts of the sea bottom, and mark it with furrows and striæ indicative of the direction of their own motion.

When we examine a chart of the American coast, and observe the deep channel and hollow submarine valleys of the Arctic current, and the sandbanks which extend parallel to this

channel from the great bank of Newfoundland to Cape Cod, we cannot avoid the conclusion that the Arctic current and its ice have great power both of excavation and deposition. On the one hand, deep hollows are cut out where the current flows over the bottom, and on the other, great banks are heaped up where the ice thaws and the force of the current is abated. I have been much struck with the worn and abraded appearance of stones and dead shells taken up from the banks off the American coast, and am convinced that an erosive power comparable to that of a river carrying sand over its bed, and materially aided by the grinding action of ice, is constantly in action under the waters of the Arctic current.[1] The unequal pressure resulting from this deposition and abrasion is not improbably connected with the slight earthquakes experienced in Eastern America, and also with the slow depression of the coast; and if we go back to that earliest of all geological periods when the Laurentian rocks of Sir Wm. Logan, constituting the Labrador coast and the Laurentide Hills, were alone above water, we may even attribute in no small degree to the Arctic current of that old time the heaping up of those thousands of feet of deposits which now constitute the great range of the Alleghany and Apalachian mountains, and form the breast bone of the American continent. In those ancient times also large stones were floated southward, and enter into the composition of very old conglomerates.

[1] At the time when this was written I had only studied stones brought up accidentally by fishermen and others from the banks of Newfoundland and elsewhere. At a later date Murray of the *Challenger* has given more ample material. He states that the bottom in the Labrador current, 100 miles from land, was found to be blue mud with 60 per cent. of sand and stones; and mentions a block of syenite weighing 490 lbs. taken up in 1,340 fathoms, and stones and pebbles of quartzite, limestone, dolomite, mica schist and serpentine, one of which was glaciated. This is the modern boulder clay produced by Greenland glaciers and the field ice of Baffin's Bay and the Labrador coast.

But such large speculations might soon carry us far from Belle-Isle, and to bring us back to the American coast and to the domain of common things, we may note that a vast variety of marine life exists in the cold waters of the Arctic current, and that this is one of the reasons of the great and valuable fisheries of Labrador, Newfoundland and Nova Scotia, regions in which the sea thus becomes the harvest field of much of the human population. On the Arctic current and its ice also floats to the southward the game of the sealers of St. John and the whalers of Gaspé.

We may now proceed to connect these statements as to the distribution of icebergs, with the glaciated condition of our continents, with the remarkable fact that the same effects now produced by the ice and the Arctic current in the Strait of Belle-Isle and the deep-current channel off the American coast, are visible all over the North American and European land north of forty degrees of latitude, and that there is evidence that the St. Lawrence valley itself was once a gigantic Belle-Isle, in which thousands of bergs worked perhaps for thousands of years, grinding and striating its rocks, cutting out its deeper parts, and heaping up in it quantities of northern *débris*. Out of this fact of the so-called glaciated condition of the surface of our continents has, however, arisen one of the great controversies of modern geology. While all admit the action of ice in distributing and arranging the materials which constitute the last coating which has been laid upon the surface of our continents, some maintain that land glaciers have done the work, others, that sea-borne ice has been the main agent employed. As in some other controversies, the truth seems to lie between the extremes. Glaciers are slow, inactive, and limited in their sphere. Floating ice is locomotive and far-travelled, extending its action to great distances from its sources. So far, the advantages are in favour of the flotation. But the work which the glacier does is done thoroughly, and,

time and facilities being given, it may be done over wide areas. Again, the iceberg is the child of the glacier, and therefore the agency of the one is indirectly that of the other. Thus, in any view we must plough with both of these geological oxen, and the controversy becomes like that old one of the Neptunists and Plutonists, which has been settled by admitting both water and heat to have been instrumental in the formation of rocks.

In the midst of these controversies a geologist resident in Great Britain or Canada should have some certain doctrine as to the question whether at that period, geologically recent, which we call the Pleistocene period, the land was raised to a great height above the sea, and covered like Greenland with a mantle of perpetual ice, or whether it was, like the strait of Belle-Isle and the banks of Newfoundland, under water, and annually ground over by icebergs, or whether, as now seems more probable, it was in part composed of elevated ridges covered with snow and sending down glaciers, and partly depressed under the level of ice-laden straits and seas.

A great advocate of the glacier theory has said that we cannot properly appreciate his view without exploring thoroughly the present glaciers of Greenland and ascertaining their effects. This I have not had opportunity to do, but I have endeavoured to do the next best thing by passing as rapidly as possible from the icebergs of Belle-Isle to the glaciers of Mont Blanc, and by asking the question whether Canada was in the Pleistocene period like the present Belle-Isle or the present Mont Blanc, or whether it partook of the character of both? and taking advantage of these two most salient points in order to elicit a reply.

Transporting ourselves, then, to the monarch of the Alps, let us suppose we stand upon the Flegere, a spur of the mountains fronting Mont Blanc, and commanding a view of the entire group. From this point the western end of the range presents the rounded summit of Mont Blanc proper, flanked by the

lower eminences of the Dome and Aiguille de Gouté, which rise from a broad and uneven plateau of *nevé* or hard snow, sending down to the plain two great glaciers or streams of ice, the Bossons and Tacony glaciers. Eastward of Mont Blanc the *nevé* or snow plateau is penetrated by a series of sharp points of rock or aiguilles, which stretch along in a row of serried peaks, and then give place to a deep notch, through which flows the greatest of all the glaciers of this side of Mont Blanc, the celebrated Mer de Glace, directly in front of our standpoint. To the left of this is another mass of aiguilles, culminating in the Aiguille Verte. This second group of needles descends into the long and narrow Glacier of Argentiere, and beyond this we see in the distance the Glacier and Aiguille de Tour. As seen from this point, it is evident that the whole system of the Mont Blanc glaciers originates in a vast mantle of snow capping the ridge of the chain, and extending about twenty miles in length, with a breadth of about five miles. This mass of snow being above the limits of perpetual frost, would go on increasing from year to year, except so far as it might be diminished by the fall of avalanches from its sides, were it not that its plasticity is sufficient to enable the frozen mass to glide slowly down the valleys, changing in its progress into an icy stream, which, descending to the plain, melts at its base and discharges itself in a torrent of white muddy water. The Mont Blanc chain sends forth about a dozen of large glaciers of this kind, besides many smaller ones. Crossing the valley of Chamouni, and ascending the Montanvert to a height of about 6,000 feet, let us look more particularly at one of these glaciers, the Mer de Glace. It is a long valley with steep sides, about half a mile wide, and filled with ice, which presents a general level or slightly inclined surface, traversed with innumerable transverse cracks or crevasses, penetrating apparently to the bottom of the glacier, and with slippery sloping edges of moist ice threatening at every step to

plunge the traveller into the depths below. Still the treacherous surface is daily crossed by parties of travellers, apparently without any accident. The whole of the ice is moving steadily along the slope on which it rests, at the rate of eight to ten inches daily—the rate of motion is less in winter and greater in summer; and farther down, where the glacier goes by the name of the Glacier du Bois, and descends a steeper slope, its rapidity is greater; and at the same time by the opening of immense crevasses its surface projects in fantastic ridges and pinnacles. The movements and changes in the ice of these glaciers are in truth very remarkable, and show a mobility and plasticity which at first sight we should not have been prepared to expect in a solid like ice.[1] The crevasses become open or closed, curved upwards or downwards, perpendicular or inclined, according to the surface upon which the glacier is moving, and the whole mass is crushed upward or flattens out, its particles evidently moving on each other with much the same result as would take place in a mass of thick mud similarly moving. On the surface of the ice there are a few boulders and many stones, and in places these accumulate in long irregular bands indicating the lines of junction of the minor ice streams coming in from above to join the main glacier. At the sides are two great mounds of rubbish, much higher than the present surface of the glacier. They are called the lateral moraines, and consist of boulders, stones, gravel and sand, confusedly intermingled, and for the most part retaining their sharp angles. This mass of rubbish is moved downward by the glacier, and with the stones constituting the central moraine,

[1] I need scarcely say that I adopt the explanation of glacier motion given by Forbes. "The fuller consideration of the physical properties of glacier ice leads essentially to the same conclusions as those to which Forbes was led forty-one years ago by the study of the larger phenomena of glacier motion, that is, that the motion is that of a slightly viscous mass, partly sliding upon its bed, partly shearingupon itself under the influence of gravity."—Trotter, Proc. Royal Society of London, xxxviii. 107.

is discharged at the lower end, accumulating there in the mass of detritus known as the terminal moraine.

Glaciers have been termed rivers of ice; but there is one respect in which they differ remarkably from rivers. They are broad above and narrow below, or rather, their width above corresponds to the drainage area of a river. This is well seen in a map of the Mer de Glace. From its termination in the Glacier du Bois to the top of the Mer de Glace proper, a distance of about three and a half miles, its breadth does not exceed half a mile, but above this point it spreads out into three great glaciers, the Geant, the Du Chaud, and the Talefre, the aggregate width of which is six or seven miles. The snow and ice of a large interior tableland or series of wide valleys are thus emptied into one narrow ravine, and pour their whole accumulations through the Mer de Glace. Leaving, however, the many interesting phenomena connected with the motion of glaciers, and which have been so well interpreted by Saussure, Agassiz, Forbes, Hopkins, Tyndall, and others, we may consider their effects on the mountain valleys in which they operate.

1. They carry quantities of *débris* from the hill tops and mountain valleys downward into the plains. From every peak, cliff and ridge the frost and thaw are constantly loosening stones and other matters which are swept by avalanches to the surface of the glacier, and constitute lateral moraines. When two or more glaciers unite into one, these become medial moraines, and at length are spread over and through the whole mass of the ice. Eventually all this material, including stones of immense size, as well as fine sand and mud, is deposited in the terminal moraine, or carried off by the streams.

2. They are mills for grinding and triturating rock. The pieces of rock in the moraine are, in the course of their movement, crushed against one another and the sides of the valley, and are cracked and ground as if in a crushing mill. Further

the stones on the surface of the glacier are ever falling into crevasses, and thus reach the bottom of the ice, where they are further ground one against another and the floor of rock. In the movement of the glacier these stones seem in some cases to come again to the surface, and their remains are finally discharged in the terminal moraine, which is the waste-heap of this great mill. The fine material which has been produced, the flour of the mill, so to speak, becomes diffused in the water which is constantly flowing from beneath the glacier, and for this reason all the streams flowing from glaciers are turbid with whitish sand and mud.

The Arve, which drains the glaciers of the north side of Mont Blanc, carries its burden of mud into the Rhone, which sweeps it, with the similar material of many other Alpine streams, into the Mediterranean, to aid in filling up the bottom of that sea, whose blue waters it discolours for miles from the shore, and to increase its own ever-enlarging delta, which encroaches on the sea at the rate of about half a mile per century. The upper waters of the Rhone, laden with similar material, are filling up the Lake of Geneva; and the great deposit of "loess" in the alluvial plain of the Rhine, about which Gaul and German have contended since the dawn of European history, is of similar origin. The mass of material which has thus been carried off from the Alps, would suffice to build up a great mountain chain. Thus, by the action of ice and water—

> "The mountain falling cometh to naught,
> And the rock is removed out of its place."

Many observers who have commented on these facts have taken it for granted that the mud thus sent off from glaciers, and which is so much greater in amount than the matter remaining in their moraines, must be ground from the bottom of the glacier valleys, and hence have attributed to these

glaciers great power of cutting out and deepening their valleys. But this is evidently an error, just as it would be an error to suppose the flour of a grist mill ground out of the mill stones. Glaciers, it is true, groove and striate and polish the rocks over which they move, and especially those of projecting points and slight elevations in their beds; but the material which they grind up is principally derived from the exposed frost-bitten rocks above them, and the rocky floor under the glacier is merely the nether mill stone against which those loose stones are crushed. The glaciers, in short, can scarcely be regarded as cutting agents at all, in so far as the sides and bottoms of their beds are concerned, and in the valleys which the old glaciers have abandoned, it is evident that the torrents which have succeeded them have far greater cutting power.

The glaciers have their periods of advance and of recession. A series of wet and cool summers causes them to advance and encroach on the plains, pushing before them their moraines, and even forests and human habitations. In dry and warm summers they shrink and recede. Such changes seem to have occurred in bygone times on a gigantic scale. All the valleys below the present glaciers present traces of former glacier action. Even the Jura mountains seem at one time to have had glaciers. Large blocks from the Alps have been carried across the intervening valley and lodged at great heights on the slopes of the Jura, leading the majority of the Swiss and Italian geologists to believe that even this great valley and the basin of Lake Leman were once filled with glacier ice. But, unless we can suppose that the Alps were then vastly higher than at present, this seems scarcely to be physically possible, and it seems more likely that the conditions were just the reverse of those supposed, namely, that the low land was submerged, and that the valley of Lake Leman was a strait like Belle-Isle, traversed by powerful currents and receiving icebergs from both Jurassic and Alpine glaciers, and probably

from farther north. One or other supposition is required to account for the appearances, which may be explained on either view. The European hills may have been higher and colder, and changes of level elsewhere may have combined with this to give a cold climate with moisture; or a great submergence may have left the hills as islands, and may have so reduced the temperature by the influx of arctic currents and ice, as to enable the Alpine glaciers to descend to the level of the sea. Now, we have evidence of such submergence in the beds of sea-shells and travelled boulders scattered over Europe, while we also have evidence of contemporaneous glaciers, in their traces on the hills of Wales and Scotland and elsewhere, where they do not now occur.

I have long maintained that in America all the observed facts imply a climate no colder than that which would have resulted from the subsidence which we know to have occurred in the temperate latitudes in the Pleistocene period, and though I would not desire to speak so positively about Europe, I confess to a strong impression that the same is the case there, and that the casing of glacier ice imagined by many geologists, as well as the various hypotheses which have been devised to account for it, and to avoid the mechanical, meteorological, and astronomical difficulties attending it, are alike gratuitous and chimerical, as not being at all required to account for observed facts, and being contradictory, when carefully considered, to known physical laws as well as geological phenomena.[1]

Carrying with me a knowledge of the phenomena of the glacial drift as they exist in North America, and of the modern ice drift on its shores, I was continually asking myself the question—To what extent do the phenomena of glacier drift and erosion resemble these? and standing on the moraine of the Bosson glacier, which struck me as more like boulder clay

[1] *Canadian Naturalist*, vols. viii. and ix. *Geological Magazine*, December, 1865.

than anything else I saw in the Alps, with the exception of some recent avalanches, I jotted down what appeared to me to be the most important points of difference. They stand thus :—

1. Glaciers heap up their *débris* in abrupt ridges. Floating ice sometimes does this, but more usually spreads its load in a more or less uniform sheet.[1]

2. The material of moraines is all local. Floating ice carries its deposits often to great distances from their sources.

3. The stones carried by glaciers are mostly angular, except where they have been acted on by torrents. Those moved by floating ice are more often rounded, being acted on by the waves and by the abrading action of sand drifted by currents.

4. In the marine glacial deposits mud is mixed with stones and boulders. In the case of land glaciers, most of this mud is carried off by streams and deposited elsewhere.

5. The deposits from floating ice may contain marine shells. Those of glaciers cannot, except where, as in Greenland and Spitzbergen, glaciers push their moraines out into the sea.

6. It is of the nature of glaciers to flow in the deepest ravines they can find, and such ravines drain the ice of extensive areas of mountain land. Floating ice, on the contrary, acts with greatest ease on flat surfaces or slight elevations in the sea bottom.

7. Glaciers must descend slopes and must be backed by large supplies of perennial snow. Floating ice acts independently, and being water-borne may work up slopes and on level surfaces.

8. Glaciers striate the sides and bottoms of their ravines very unequally, acting with great force and effect only on those places where their weight impinges most heavily. Float-

[1] Under floating ice I include floe, pack, and bordage ice as well as bergs.

ing ice, on the contrary, being carried by constant currents and over comparatively flat surfaces, must striate and grind more regularly over large areas, and with less reference to local inequalities of surface.

9. The direction of the striæ and grooves produced by glaciers depends on the direction of valleys. That of floating ice, on the contrary, depends upon the direction of marine currents, which is not determined by the outline of the surface, but is influenced by the large and wide depressions of the sea bottom.

10. When subsidence of the land is in progress, floating ice may carry boulders from lower to higher levels. Glaciers cannot do this under any circumstances, though in their progress they may leave blocks perched on the tops of peaks and ridges.

I believe that in all these points of difference the boulder clay and drift on the lower lands of Canada and other parts of North America, correspond rather with the action of floating ice than of land ice; though certainly with glaciers on such land as existed at the different stages of the submergence, and these glaciers drifting stones and earthy matter in different directions from higher land toward the sea. More especially is this the case in the character of the striated surfaces, the bedded distribution of the deposits, the transport of material up the natural slope, the presence of marine shells, and the mechanical and chemical characters of the boulder clay. In short, those who regard the Canadian boulder clay as a glacier deposit, can only do so by overlooking essential points of difference between it and modern accumulations of this kind.

I would wish it here to be distinctly understood, that I do not doubt that at the time of the greatest Pleistocene submergence of Eastern America, at which time I believe the greater part of the boulder clay was formed, and the more important striation effected, the higher hills then standing as islands would

be capped with perpetual snow, and through a great part of the year surrounded with heavy field and barrier ice, and that in those hills there might be glaciers of greater or less extent. Further, it should be understood that I regard the boulder clays of the St. Lawrence valley as of different ages, ranging from those of the early Pleistocene to that now forming in the Gulf of St. Lawrence; and that during these periods great changes of level occurred. Further, that this boulder clay shows in every place where I have been able to examine it, evidence of subaqueous accumulation, in the presence of marine shells or in the unweathered state of the rocks and minerals enclosed in it; conditions which, in my view, preclude any reference of it to glacier action, except possibly in some cases to that of glaciers stretching from the land over the margin of the sea, and forming under water a deposit equivalent in character to the *boue glaciare* of the bottom of the Swiss glaciers. But such a deposit must have been local, and would not be easily distinguishable from the marine boulder clay. It is of some interest to compare Canadian deposits with those of Scotland,[1] which in character and relations so closely resemble those of Canada; but I confess several of the facts lead me to infer that much of what has been regarded as of subaërial origin in that country must really be marine, though whether deposited by icebergs or by the fronts of glaciers terminating in the sea, I do not pretend to determine.[2] It must, however, be observed that the antecedent probability of a glaciated condition is much greater in the case of Scotland than in that of Canada, from the high northern latitude of the former, its hilly and maritime character, and the fact that its present

[1] *Journal of Geological Society.* Papers by Jamieson, Bryce, Crosskey, and Geikie.

[2] Geikie, Trans. Royal Society of Edin. Geikie assigns a more complicated structure than appears to be present in Canada; but there are Canadian equivalents of the principal glacial periods which he assumes.

exemption from glaciers is due to what may be termed exceptional and accidental geographical conditions; more especially to the distribution of the waters of the Gulf Stream, which might be changed by a comparatively small subsidence in Central America. To assume the former existence of glaciers in a country in north latitude 56°, and with its highest hills, under the present exceptionally favourable conditions, snow-capped during most of the year, is a very different thing from assuming a covering of continental ice over wide plains more than ten degrees farther south, and in which, even under very unfavourable geographical accidents, no snow can endure the summer sun, even in mountains several thousand feet high. Were the plains of North America submerged and invaded by the cold arctic currents, the Gulf Stream being at the same time turned into the Pacific, the temperature of the remaining North American land would be greatly diminished; but under these circumstances the climate of Scotland would necessarily be reduced to the same condition with that of South Greenland or Northern Labrador. As we know such a submergence of America to have occurred in the Pleistocene period, it does not seem necessary to have recourse to any other cause for either side of the Atlantic. It would, however, be a very interesting point to determine, whether in the Pleistocene period the greatest submergence of America coincided with the greatest submergence of Europe, or otherwise. It is quite possible that more accurate information on this point might remove some present difficulties. I think it much to be desired that the many able observers now engaged on the Pleistocene of Europe, would at least keep before their minds the probable effects of the geographical conditions above referred to, and inquire whether a due consideration of these would not allow them to dispense altogether with the somewhat extravagant theories of glaciation now agitated.

The preceding pages give the substance of my conclusions

of twenty-four years ago. I give those of to-day from a paper of 1891,[1] relating to Eastern Canada only :—

These conclusions have, in my judgment, been confirmed, and their bearing extended, more especially by the researches of Mr. Chalmers, who has shown in the most convincing way that glaciers proceeding from local centres along with sea-borne ice, may have been the agents in glaciating surfaces and transporting boulders in Nova Scotia and New Brunswick. Taken in connection with the observations of Dr. Dawson and Mr. McConnell in the Cordillera region of the west, and those of Dr. Bell, Dr. Ells, Mr. Low, and others in the Laurentian country north of the St. Lawrence, and in the Province of Quebec, we may now be said to know that there was not, even at the height of the glacial refrigeration of America, a continental ice sheet, but rather several distinct centres of ice action, —one in the Cordillera of the West, one on the Laurentian V-shaped axis, and one on the Appalachians, with subordinate centres on isolated masses like the Adirondacks, and at certain periods even on minor hills like those of Nova Scotia. It would further seem that, in the west at least, elevation of the mountain ridges coincided with depression of the plains. In Newfoundland also, it would appear from the observations of Captain Kerr, with which those of Mr. Murray are in harmony,[2] though they have been differently interpreted, that the gathering ground of ice was in the interior of the island, and that glaciers moved thence to the coasts, but principally to the east coast, as was natural from the conformation of the land and the greater supply of moisture from the Atlantic.

The labours of Murray in Newfoundland, of Matthew, Chalmers, Bailey, and others, in Nova Scotia and New Brunswick, have considerably enlarged our knowledge of Pleistocene fossils, showing, however, that the marine fauna is the same

[1] Supplement to 4th edition of "Acadian Geology," 1891.

[2] Trans. Royal Society of Canada, vol. i.

with that of the beds of like age in the St. Lawrence valley, and with the existing fauna of the Labrador coast and colder portions of the Gulf and River St. Lawrence, as ascertained by Prickard, Whiteaves, and the writer. It would seem that throughout this region, the 60 feet and the 600 feet terraces were the most important with reference to these marine remains, and that their chief repository is in the Upper Leda Clay, a marine deposit intermediate between the Lower and Upper boulder drift, and corresponding to the interglacial beds of the interior of America.

The general conditions of the period may be thus summarized :—

In this district, and the eastern part of North America generally, it is, I think, universally admitted that the later Pliocene period was one of continental elevation, and probably of temperate climate. The evidence of this is too well known to require re-statement here. It is also evident, from the raised beaches holding marine shells, extending to elevations of 600 feet, and from drift boulders reaching to a far greater height, that extensive submergence occurred in the middle and later Pleistocene. This was the age of the beds I have named the *Leda* clays and *Saxicava* sands, found at heights of 600 feet above the sea in the St. Lawrence valley, nearly as far west as Lake Ontario.

It is reasonable to conclude that the till or boulder clay, under the Leda clay, belongs to the earliest period of probably gradual subsidence, accompanied with a severe climate, and with snow and glaciers on all the higher grounds, sending glaciated stones into the sea. This deduction agrees with the marine shells, polyzoa, and cirripedes found in the boulder deposits on the lower St. Lawrence, with the unoxidized character of the mass, which proves subaqueous deposition, with the fact that it contains soft boulders, which would have crumbled if exposed to the air, with its limitation to the lower levels and

absence on the hillsides, and with the prevalent direction of striation and boulder drift from the north-east.[1]

All these indications coincide with the conditions of the modern boulder drift on the lower St. Lawrence and in the Arctic regions, where the great belts and ridges of boulders accumulated by the coast ice would, if the coast were sinking, climb upward and be filled in with mud, forming a continuous sheet of boulder deposit similar to that which has accumulated and is accumulating on the shores of Smith's Sound and elsewhere in the Arctic, and which, like the older boulder clay, is known to contain both marine shells and driftwood.[2]

The conditions of the deposit of "till" diminished in intensity as the subsidence continued. The gathering ground of local glaciers was lessened, the ice was no longer limited to narrow sounds, but had a wider scope, as well as a freer drift to the southward, and the climate seems to have been improved. The clays deposited had few boulders and many marine shells, and to the west and north there were land-producing plants akin to those of the temperate regions; and in places only slightly elevated above the water, peaty deposits accumulated. The shells of the Leda clay indicate depths of less than 100 fathoms. The numerous Foraminifera, so far as have been observed, belong to this range, and I have never seen in this clay the assemblage of foraminiferal forms now dredged from 200 to 300 fathoms in the Gulf of St. Lawrence.

I infer that the subsidence of the Leda clay period and of the interglacial beds of Ontario belongs to the time of the sea beaches from 450 to 600 feet in height, which are so marked and extensive as to indicate a period of repose. In this period

[1] Notes on the Post-Pliocene *Canadian Naturalist*, *op. cit.*; also Paper by the author on Boulder Drift at Metis, *Canadian Record of Science*, vol. ii., 1886, p. 36, *et seq.*

[2] For references see "Royal Society's Arctic Manual," London, 1875, *op. cit.*

there were marine conditions in the lower and middle St. Lawrence and in the Ottawa valley, and swamps and lakes on the upper Ottawa and the western end of Lake Ontario. It is quite probable, nay, certain, that during this interglacial period re-elevation had set in, since the upper Leda clay and the Saxicava sand indicate shallowing water, and during this re-elevation the plant-covered surface would extend to lower levels.

This, however, must have been followed by a second subsidence, since the water-worn gravels and loose, far-travelled boulders of the later drift rose to heights never reached by the till or the Leda clay, and attained to the tops of the highest hills of the St. Lawrence valley, 1,200 feet in height, and elsewhere to still greater elevations. This second boulder drift must have been wholly marine, and probably not of long duration. It shows no evidence of colder climate than that now prevalent, nor of extensive glaciers on the mountains; and it was followed by a paroxysmal elevation in successive stages till the land attained even more than its present height, as subsidence is known to have been proceeding in modern times.

I am quite aware that the above sequence and the causes assumed are somewhat different from those held by many geologists with reference to regions south of Canada; but must hold that they are the only rational conclusions which can be propounded with reference to the facts observed from the parallel of 45° to the Arctic Ocean.

My own observations have been chiefly in the eastern part of North America. My son, Dr. G. M. Dawson, has much more ably and thoroughly explored those of the west; and after describing the immense Cordilleran ice mass which extended for a length of 1,200 miles along the mountains of British Columbia and discharged large glaciers to the north, as well as to the west and south, and stating his reasons for believing in that differential elevation and depression which

caused the greatest height of the mountains to coincide with the greatest depression of the plains, and *vica versa*, and showing the Cordilleran glacier must have been separated by a water area from that of the Laurentide hills on the east, thus concludes :—

"It is now distinctly known, as the result of work done under the auspices of the Geological Survey of Canada, and more particularly of observations by the writer and his colleagues, Messrs. McConnel and Tyrrell, that the extreme margins of the western and eastern glaciated areas of the continent barely overlap, and then only to a very limited extent, while the two great centres of dispersion were entirely distinct. For numerous reasons which cannot be here entered into, the writer does not consider it probable, or even possible, that the great confluent glacier of the north-eastern part of the continent extended at any time far into the area of the great plains; but erratics and drift derived from this ice mass did so extend, and are found between the 49th and 50th parallels, stranded on the surface of moraines produced by the large local glaciers of the Rocky Mountains. Recognising, however, the essential separateness of the western and eastern confluent ice masses, and the fact that it is no longer appropriate to designate one of these the "continental glacier," the writer ventures to propose that the eastern *mer de glace* may appropriately be named the great *Laurentide glacier*, while its western fellow is known as the "*Cordilleran glacier*." It may be added that there is good evidence to show that both the Laurentide and Cordilleran glaciers discharged into open water to the north."

These conclusions, based on a large induction of facts applying to a very large area of the North American Continent, coincide with my own observations in the east, and with the inferences deducible from the present condition of Greenland and Arctic America.

When extreme glacialists point to Greenland and ask us to

believe that in the Glacial age the whole continent of North America, as far south as the latitude of 40°, was covered with a continuous glacier, having a wide front, and thousands of feet thick, we may well ask, first, what evidence there is that Greenland or even the Antarctic continent is at present in such a condition; and, secondly, whether there exists a possibility that the interior of a great continent could ever receive so large an amount of precipitation as that required. So far as present knowledge exists, it is certain that the meteorologist and the physicist must answer both questions in the negative. In short, perpetual snow and glaciers must be local, and cannot be continental, because of the vast amount of evaporation and condensation required. These can only be possible where comparatively warm seas supply moisture to cold and elevated land, and this supply cannot, in the nature of things, penetrate far inland. The actual condition of interior Asia and interior America in the higher northern latitudes affords positive proof of this. In a state of partial submergence of our northern continents, we can readily imagine glaciation by the combined action of local glaciers and great ice floes; but in whatever way the phenomena of the boulder clay and of the so-called "terminal moraines" are to be accounted for, the theory of a continuous continental glacier must be given up.

The great interior plain of western Canada, between the Laurentian axis on the east and the Rocky Mountains on the west, is seven hundred miles in breadth, and is covered with glacial drift, presenting one of the greatest examples of this deposit in the world. Proceeding eastward from the base of the Rocky Mountains, the surface, at first more than 4,000 feet above the sea level, descends by successive steps to 2,500 feet, and is based on Cretaceous and Laramie rocks, covered with boulder clay and sand, in some places from one hundred to two hundred feet in depth, and filling up pre-existing hollows, though itself sometimes piled into ridges. Near the Rocky

Mountains the bottom of the drift consists of gravel not glaciated. This extends to about one hundred miles east of the mountains, and must have been swept by water out of their valleys. The boulder clay resting on this deposit is largely made up of local *débris*, in so far as its paste is concerned. It contains many glaciated boulders and stones from the Laurentian region to the east, and also smaller pebbles from the Rocky Mountains, so that at the time of its formation there must have been driftage of large stones for seven hundred miles or more from the east, and of smaller stones from a less distance on the west. The former kind of material extends to the base of the mountains, and to a height of more than 4,000 feet. One boulder is mentioned as being 42 × 40 × 20 feet in dimensions. The highest Laurentian boulders seen were at an elevation of 4,660 feet on the base of the Rocky Mountains. The boulder clay, when thick, can be seen to be rudely stratified, and at one place includes beds of laminated clay with compressed peat, similar to the forest beds described by Worthen and Andrews in Illinois, and the so-called interglacial beds described by Hinde on Lake Ontario. The leaf beds on the Ottawa river, and the drift trunks found in the boulder clay of Manitoba, belong to the same category, and indicate in the midst of the Glacial period many forest oases far to the north, having a temperate rather than an arctic flora. In the valleys of the Rocky Mountains opening on these plains there are evidences of large local glaciers now extinct, and similar evidences exist on the Laurentian highlands on the east. A recent paper of Dr. G. M. Dawson on the Palæography of the Rocky Mountains illustrates in a most convincing manner the changes which have occurred in the Cordillera of North America, and the differential elevation and depression which have affected its climate in the later geological periods.[1]

Perhaps the most remarkable feature of the western drift region

[1] Transactions Royal Society of Canada, 1890.

is that immense series of ridges of drift piled against an escarpment of Laramie and Cretaceous rocks, at an elevation of about 2,500 feet, and known as the "Missouri Coteau." It is in some places 30 miles broad and 180 feet in height above the plain at its foot, and extends north and south for a great distance: being, in fact, the northern extension of those great ridges of drift which have been traced south of the great lakes, and through Pennsylvania and New Jersey, and which figure on the geological maps as the edge of the continental glacier—an explanation obviously inapplicable in those western regions where they attain their greatest development. It is plain that in the north it marks the western limit of the deep water of a glacial sea, which at some periods extended much farther west, perhaps with a greater proportionate depression in going westward, and on which heavy ice from the Laurentian districts on the east was wafted southwestward by the arctic currents, while lighter ice from the Rocky Mountains was being borne eastward from these mountains by the prevailing westerly winds. We thus have in the west, on a very wide scale, the same phenomena of varying submergence, cold currents, great ice floes and local glaciers producing icebergs, to which I have attributed the boulder clay and upper boulder drift of eastern Canada. In short, we arrive at the conclusion that there never has been a continental glacier, properly so called, but that in the extreme Glacial period there have been great centres of snow and glacial action, in the Cordillera of the west, in the Laurentian plateau of the north, and in the northern Appalachians, and the Adirondacks, while the lower lands have been either submerged, or enjoying a climate habitable by hardy animals and plants.

The till or boulder clay has been called a "ground moraine," but there are really no Alpine moraines at all corresponding to it. On the other hand, it is more or less stratified, often rests on soft materials which glaciers would have swept away, some-

times contains marine shells, or passes into marine clays in its horizontal extension, and invariably in its embedded boulders and its paste, shows an unoxidized condition, which could not have existed if it had been a subaërial deposit. When the Canadian till is excavated and exposed to the air, it assumes a brown colour, owing to oxidation of its iron, and many of its stones and boulders break up and disintegrate under the action of air and frost. These are unequivocal signs of a subaqueous deposit. Here and there we find associated with it, and especially near the bottom and at the top, indications of powerful water action, as if of land torrents acting at particular elevations of the land, or heavy surf and ice action on coasts, and the attempts to explain these by glacial streams have been far from successful. A singular objection sometimes raised against the subaqueous origin of the till is its general want of marine remains; but this is by no means universal, and it is well known that coarse conglomerates of all ages are generally destitute of fossils, except in their pebbles, and it is further to be observed that the conditions of an ice-laden sea are not those most favourable for the extension of marine life, and that the period of time covered by the glacial age must have been short, compared with that represented by some of the older formations.

It follows from all this that the great "continental moraine," which the United States Geological Survey has now "delineated for several thousand miles extending from the Atlantic to the Pacific," cannot be a glacier moraine, but must be, like its great continuation northward, the Missouri coteau, a margin of sea drift, and that we must explain the whole of the drift of the American continent by the supposition, first, of a period of elevation of the hills and subsidence of the valleys in which there were great accumulations of snow on the Western Cordillera; the Laurentian axis, and the Appalachians and Adirondacks radiating in every direction from these points, while

minor areas of radiation may have temporarily existed on smaller elevations: that this was followed by a period of more equal level, in which parts of the low grounds were clothed with a temperate flora, the "Interglacial period" so called, succeeded by a second great depression, in which the high level boulders of the second boulder drift were wafted to great distances by floating ice.

The late Prof. Alexander Winchell, a man who did not hesitate to express his convictions, thus bears similar testimony:—"There has been no continental glacier. There has been no uniform southerly movement of glacier masses. There has been no persistent declivity as a *sine qua non*, down which glacier movements have taken place. The continuity of the supposed continental glacier was interrupted in the regions of the dry and treeless plains of the west; and in the interior and Pacific belts of the continent within the United States, ancient glaciation was restricted to the elevated slopes."[1] He might have added that the St. Lawrence valley was submerged and received the ends of Appalachian and Adirondack glaciers on the south-east, and those of Laurentide glaciers on the north-west.

My friend Prof. Claypole, who, however, has some hesitation, fearing, I persume, to be cast out of the synagogue for heresy, ventures to say,[2] "We deduce from the facts and arguments stated above, that all the observations of glacial action in the northern hemisphere are explicable by assuming the existence of enormous and confluent[3] glacier-systems in and about the high lands of Europe, Asia, and America, which high lands became, therefore, glacial radiants, and shed their load of ice in all directions over the lower adjacent ground, along the lines of

[1] Nov., 1890. [2] *American Geologist*, Feb., 1889.

[3] The term "confluent" is not necessary here. The glaciers of all mountain chains may be said to be more or less confluent in the nevé, from which individual glaciers radiate.

easiest flow; that this theory does no violence to the analogy of the existing order of things, requiring merely an enlargement of actual glaciers by the intensification of actual conditions: that abundant evidence can he obtained, as, for example, from Switzerland, that the present glacier system of the earth was once of sufficient magnitude to produce all the observed phenomena; that the most important glacial radiants in the northern hemisphere were, in North America, the district round Hudson Bay, New England and the Adirondacks, with certain areas in the western Cordilleras, and in Europe the Norwegian Dovrefelds and the Alps, Asia apparently possessing none of commensurate importance; that it satisfactorily explains, also, the previously puzzling absence of glacial action over the great plain of Siberia, the coldest portion of the northern temperate zone; that the belief in a vast polar ice cap, thousands of feet thick, covering the whole Arctic region, and extending almost continuously down to low latitudes, is an assumption doing violence to observed physical facts and to probability, that it is not required to account for the phenomena, and is, in fact, contradictory to some of them."

In Europe there is equally good evidence of the existence of huge glaciers on the Scandinavian mountains and the Alps, and of lesser accumulations of ice on the hills, as, for instance, those of the British Islands; but the Scandinavian boulders scattered over the plains of Great Britain must have been water borne.[1]

In connection with these extracts I would observe that the writer, and those with whom he has acted in this matter, have never held that icebergs alone, or fields of ice alone, have produced the Pleistocene deposits. Their contention has been that the period was one in which glaciers, icebergs, and field

[1] The reports of the Scottish boulder committee, and Lapworth's recent careful examination of the deposits on the East of England (*Journ. Geol. Soc.*, Aug., 1891), strongly confirm me in this opinion.

ice acted together, and along with aqueous agencies, in producing the complicated formations of this remarkable age. They have, however, objected strenuously to the sole employment of one agent to the exclusion of others, and to attributing to that agent powers and extension which obviously could not belong to it, under the known laws which regulate the movement of glaciers by the force of gravity, and the precipitation of moisture in the form of snow on mountains and plateaus. These laws show that the movement of glaciers over level surfaces, or against the slope of the ground, and their moving stones otherwise than down slopes, are physical impossibilities, and that the accumulation of snow to form glaciers can take place only on elevated and cold land, supplied with large quantities of vapour from neighbouring water. Such accumulation can under no imaginable conditions take place in the interior plains and table lands of great continents.

Applying these laws and conclusions to the whole northern hemisphere, we learn that the conditions to produce a glacial period are the diversion of the warm currents from the northern seas, the submergence of land in the temperate regions, and its invasion by cold Arctic water, and great condensation of snow on the higher lands. Whether this condensation has a tendency finally to rectify the state of affairs, by pressing down the mountains and elevating the plains, we do not know, but I should imagine that it has not; for the high lands will, in the case supposed, be lightened by denudation, while the plains will be burdened with a great weight of deposit. Perhaps we should rather look to this as the agency for depressing and submerging the plains and elevating the hills, and suppose some other and more general pressure proceeding from the great sea basins, to effect the re-elevation of the plains.

These questions suggest that of the date of the Glacial period. This subject has recently been discussed by Prestwich and others, with the result that there is no purely geological ground

for referring the Glacial age to a period so remote as that advocated by Croll on astronomical grounds. Claypole has recently discussed the matter at some length, and in a temperate spirit.[1] He takes the rate of erosion of the Niagara gorge as a measure, and shows that the Falls of St. Anthony, as described by Winchell, and all the other falls and river gorges in North America, give similar estimates, which are confirmed by the evidences of lake ridges, of the rate of erosion, and of the conditions of animal and plant life. The whole go to show that the culmination of the Glacial age may have occurred less than 10,000 years ago. He further shows that the differential elevation of Lakes Erie and Ontario, the greater ease with which the river could cut the lower part of its ravine, the probability that the part of the gorge between the whirlpool and the fall was not cut, but only cleaned out in modern times, and the possible greater flow of water in the early modern period, all tend to shorten the time required, and that, as Prestwich has inferred from other data, and the writer also in various papers, some of them of old date, the so-called post-glacial period, that of the melting away of the ice, may come within 8,000 to 10,000 years of our own time. Probably the first of these figures is the nearest to the truth,[2] so that, geologically considered, the Glacial age is very recent.

Still another question of great cosmic interest relates to the possible alternation of glacial conditions in the northern and southern hemispheres. There is evidence of drift in the southern part of South America, similar to that in the north ; but was it deposited at the same time ? If we could be sure that it was not, many difficulties would be removed. The southern hemi-

[1] Trans. Edinburgh Geol. Soc., vol. v., 1888.

[2] Upham, one of the ablest and most experienced of the Glacial geologists in the United States, in a recent paper on the causes of the glacial period, states similar conclusions, and adduces the evidence of Gilbert, Andrews, Wright, Emerson and others in the same sense.

sphere is at present emphatically the ocean hemisphere; the northern, the land hemisphere. Perhaps these conditions may be capable of being reversed, in which case the periods of depression in the south may have corresponded with those of elevation in the north. One thing which we know is, that there is a polar ice ring, not an ice cap, for we do not know what is within its edges at the South Pole, about 2,000 miles in diameter, and this in the only circumstances in which it can exist, namely, surrounded by a vast ocean furnishing it with abundant aqueous vapour. We also know that from this ice ring radiate glaciers, carrying *débris*, with which the sea bottom is strown half way to the equator. If continents were elevated out of the Southern Ocean, we should probably have on their surfaces glacial deposits more widespread and continuous than any remaining on the continents of the northern hemisphere, and like some of them thinning out to a terminal edge or border, instead of a terminal moraine like that of a glacier.[1] Thus we may say with some truth that the southern hemisphere is now passing through one phase of the Glacial period.

I have often thought that in the southern hemisphere the condition of Kerguelen Island and Heard Island, as described in the reports of the *Challenger*,[2] must very nearly represent the state of some mountain ranges and peaks in North America in the Glacial age. Heard Island, in S. latitude 53° 2′, is a mountain peak 6,000 feet high, and 25 miles in length. It sends down large glaciers to the sea. In its larger neighbour, Kerguelen, the glaciers do not reach the sea; but there is evidence that at one time they did. It is still more curious that, in Kerguelen the modern ice overlies late tertiary deposits, holding remains of large trees, indicating a more continental condition and mild climate at no very remote period.

[1] This is now admitted by Chamberlain and others to be the case with the oldest boulder clay on the American continent.

[2] Vol. i. p. 370, etc.

The glaciers of Heard Island and Kerguelen have, no doubt, been carrying down moraine material into the sea, and this is certainly done on a still greater scale by those of the Antarctic continent. This sends off bergs which fill the whole ocean south of 60°, and float much farther north. Some of them have been seen 2,000 feet long and 200 high, and though most of the boulders they contain are necessarily concealed, yet masses of rock, supposed to weigh many tons, have been seen on them. The whole sea bottom off this continent, as far south as 64°, consists of blue mud, with boulders and pebbles, some of them glaciated, and farther north there is, as far as 47 degrees of latitude, a considerable percentage of drift material, and this sometimes in depths of 1,950 fathoms. It is evident that, if large areas of the southern hemisphere were elevated into land, we should have phenomena to deal with not much unlike those of North America at present.

Perhaps no discussion carries with it more of warning to geologists to exercise caution in framing theories than this of the great ice age; and if the collapse of extreme views on this subject shall have the effect of inducing geologists to keep within the limits of well-ascertained facts and sound induction, to adhere to the Lyellian doctrine of modern causes to explain ancient phenomena, and to bear in mind that most great effects involve not one cause, but many co-operating causes, it may lead to consequences beneficial to science; and so, emerging from the cold shadows of the continental glacier, we may find ourselves in the sunshine of truth.

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CAUSES OF CLIMATAL CHANGE.

DEDICATED TO

DR. T. STERRY HUNT, F.R.S.,

WHOSE WORK IN

THE CHEMICAL AND COSMICAL RELATIONS OF GEOLOGY

IS BEYOND ALL PRAISE,

AND IS DESTINED TO COMMAND

IN THE FUTURE

EVEN GREATER ACCEPTANCE THAN IN THE PAST.

Various Theories as to Changes of Climate—The Astronomical Theory of Croll—The Geographical Theory of Lyell — Objections of a Geological Character to the Former—Testimony of Geology and Physical Geography in Favour of the Latter



A

B

North America in Periods of Warm and Cold Submergence.
(*A*) Early Cretaceous. (*B*) Glacial or Pleistocene.

CHAPTER XIV.

CAUSES OF CLIMATAL CHANGE.

THE subject of this chapter is one which has been in dispute ever since I began to read anything on geology, nearly sixty years ago. It ought to have been settled, but up to to-day one finds in geological works and papers—especially those relating to the Glacial age—the most divergent views; and in the writings of men not geologists, it is not unusual to find exploded theories gravely stated as established facts of science. The subject is one which I cannot hope to make interesting, but if the reader will wade through a short chapter, he will be able to find some of the data on which statements on this subject in other papers of this series are based.

Mr. Searles V. Wood, in an able summary of the possible causes of the succession of cold and warm climates in the northern hemisphere, enumerates no fewer than seven theories which have met with more or less acceptance, and he might have added an eighth. These are:—

(1) The gradual cooling of the earth from a condition of original incandescence.

(2) Changes in the obliquity of the ecliptic.

(3) Changes in the position of the earth's axis of rotation.

(4) The effect of the precession of the equinoxes, along with changes of the eccentricity of the earth's orbit.

(5) Variations in the amount of heat given off by the sun.

(6) Differences in the temperature of portions of space passed through by the earth.

(7) Differences in the distribution of land and water in connection with the flow of oceanic currents.

(8) Variations in the properties of the atmosphere with reference to its capacity for allowing the radiation of heat.

Something may be said in favour of all these alleged causes; but as efficient in any important degree in producing the cold and warm climates of the Tertiary period, the greater number of them may be dismissed as incapable of effecting such results, or as altogether uncertain with reference to the fact of their own occurrence.

(1) That the earth and the sun have diminished in heat during geological time seems probable; but physical and geological facts alike render it certain that this influence could have produced no appreciable effect, even in the times of the earliest animals and plants, and certainly not in the case of Tertiary floras or faunas.

(2) The obliquity of the ecliptic is not believed by astronomers to have changed to any great degree, and its effect would be merely a somewhat different distribution of heat in different periods of the year.

(3) Independently of astronomical objections, there is good geological evidence that the poles of the earth must have been nearly in their present places from the dawn of life until now. From the Laurentian upward, those organic limestones which mark the areas where warm and shallow equatorial water was spreading over submerged continents, are so disposed as to prove the permanence of the poles. In like manner all the great foldings of the crust of the earth have followed lines which are parts of great circles tangent to the existing polar circles. So, also, from the Cambrian age the great drift of sediment from the north has followed the line of the existing Arctic currents from the north-east to the south-west, throwing itself, for example, along the line of the Appalachian uplifts in Eastern America, and against the ridge of the Cordilleras in the west.

(4) The effects of change of eccentricity and precession have been so ably urged by Croll, and recently by Ball, and have so strongly influenced the minds of those who are not working geologists, that they deserve a more detailed notice.

(5) The heat of the sun is known to be variable, and the eleven years' period of sun spots has recently attracted much attention as producing appreciable effects on the seasons. There may possibly be longer cycles of solar energy; or the sun may be liable, like some variable stars, to paroxysms of increased energy. Such changes are possible, but we have no evidence of their occurrence, and they could not account for periods of refrigeration of limited duration like the Glacial age.

(6) It has been supposed that the earth may have at different times traversed more or less heated zones of space, giving alternations of warm and cold temperature. No such differences in space are, however, known, nor does there seem any good ground for imagining their existence.

(7) The differences in the form and elevation of our continents, and in the consequent distribution of surfaces of different absorbent and radiating power, and of the oceanic currents, are known causes of climatal change, and have been referred to in these papers as competent to account for many, at least, of the phenomena.

(8) Reference has already been made, in connection with the distribution of plants, to the possibility that the primeval atmosphere was richer in carbon than that of more modern times, and that this might operate to produce diminution of radiation, and consequent uniformity of temperature; but this cause could not have been efficient in the later geological periods.

There may thus be said to remain two theories of those enumerated by Wood, to which more detailed consideration may be given, namely, numbers four and seven, which may be named

respectively those of Croll and Lyell, or the astronomical and geographical theories.

The late Mr. Croll has, in his valuable work "Climate and Time," and in various memoirs, brought forward an ingenious astronomical theory to account for changes of climate. This theory, as stated by himself, is that when the eccentricity of the earth's orbit is at a high value, and the northern winter solstice is in perihelion, agencies are brought into operation which make the south-east trade winds stronger than the north-east, and compel them to blow over upon the northern hemisphere as far as the Tropic of Cancer. The result is that all the great equatorial currents of the ocean are impelled into the northern hemisphere, which thus, in consequence of the immense accumulation of warm water, has its temperature raised, so that ice and snow must, to a great extent, disappear from the Arctic regions. In the prevalence of the converse conditions the Arctic zone becomes clad in ice, and the southern has its temperature raised.

At the same time, according to Croll's calculations, the accumulation of ice on either pole would tend, by shifting the earth's centre of gravity, to raise the level of the ocean and submerge the land on the colder hemisphere. Thus a submergence of land would coincide with a cold condition, and emergence with increasing warmth. Facts already referred to, however, show that this has not always been the case, but that in many cases submergence was accompanied with the influx of warm equatorial waters and a raised temperature, this apparently depending on the question of local distribution of land and water; and this, in its turn, being regulated not always by mere shifting of the centre of gravity, but by foldings occasioned by contraction, by equatorial subsidences resulting from the retardation of the earth's rotation, and by the excess of material abstracted by ice and frost from the Arctic regions, and drifted southward along the lines of arctic currents. This drift-

ing must in all geological times have greatly exceeded, as it certainly does at present, the denudation caused by atmospheric action at the equator, and must have tended to increase the disposition to equatorial collapse occasioned by retardation of rotation.[1]

While such considerations as those above referred to tend to reduce the practical importance of Mr. Croll's theory, on the other hand they tend to remove one of the greatest objections against it—namely, that founded on the necessity of supposing that glacial periods recur with astronomical regularity in geological time. They cannot do so if dependent on other causes inherent in the earth itself, and producing important movements of its crust.

Sir Robert Ball has in a recent work very ingeniously improved this theory by showing that Croll was mistaken in assigning equal amounts of heat to the earth, as a whole, in the periods of greater and less eccentricity. This would tend to augment the effect of astronomical revolutions as causes of difference of temperature; but has no bearing on the more serious geological objections to the theory in question.

A fatal objection, however, to Croll's theory, the force of which has been greatly increased by recent discoveries, is that the astronomical causes which he adduces would place the close of the last Glacial period at least 80,000 years ago, whereas it is now certainly known from geological facts that the close of the last Glacial period cannot be older than about an eighth or a tenth of that time. This difficulty seems to have caused the greater number of geologists, specially acquainted with the later geological periods, to regard this theory as quite inapplicable to the facts.

[1] Croll, in "Climate and Time," and in a note read before the British Association in 1876, takes an opposite view; but this is clearly contrary to the facts of sedimentation, which show a steady movement of *débris* toward the south and south-west.

We are thus obliged to fall back upon the old Lyellian theory of geographical changes, with such modifications as recent discoveries have rendered necessary. Taking this as our guide, we reach at once the important conclusion that the movements and distribution of animals and plants, however dependent on climate, altitude and depth, have, when regarded in connection with geological time, been primarily determined by those great movements of the crust of the earth which have established our islands, continents and ocean depths. These geographical changes have also in connection with animal and vegetable growth, deposition of sediments and volcanic ejections, fixed even the stations, soils and exposures of plants and animals. Thus, subject to those great astronomical laws which regulate the temperature of our planet as a whole, our attention may be restricted to the factors of physical geography itself. We must, however, carry with us the idea that though the great continents and the ocean depths may have been fixed throughout geological time, their relative elevations, and consequently their limits, have varied to a great extent, and are constantly changing.

We must also remember that something more than mere cold is necessary to produce a glacial period. It has sometimes been assumed that the tendency of an exceptionally cold winter would necessarily be to accumulate so great a quantity of snow and ice, that these could not be removed in the short though warm summer, and so would go on accumulating from year to year. Actual experience and observation do not confirm this supposition. In those parts of North America which have a long and severe winter, the amount of snow deposited is not in proportion to the lowness of the temperature, but, on the contrary, the greatest precipitation of snow takes place near the southern margin of a cold area, and the snow disappears with great rapidity when the spring warmth sets in. Nor is there, as has been imagined, any tendency to the production of fogs and

mists which have been invoked as agencies to shield the snow from the sun. In North America the melting snow is ordinarily carried off as liquid water, or as invisible vapour, and the sky is usually clear when the snow is melting in spring. It is only when warm and moist winds are exceptionally thrown upon the snow-covered land that clouds are produced; and when this is the case, the warm rain that ensues promotes the melting of the snow. Thus there is no possibility of continued accumulations of snow on the lower parts of our continents, under any imaginable conditions of climate. It is only on elevated lands in high latitudes and near the ocean, like Greenland and the Antarctic continent, that such permanent snow-clad conditions can occur, except on mountain tops. Wallace and Wœickoff[1] very properly maintain, in connection with these facts, that permanent ice and snow cannot under any ordinary circumstances exist in low lands, and that high land and great precipitation are necessary conditions of glaciers. The former, however, attaches rather too much importance to snow and ice as cooling agents; for though it is true that they absorb a large amount of heat in passing from the solid to the liquid state, yet the quantity of snow or ice to be melted in spring is so small in comparison with the vast and continuous pouring of solar heat on the surface, that a very short time suffices for the liquefaction of a deep covering of snow. The testimony of Siberian travellers proves this, and the same fact is a matter of ordinary observation in North America.

Setting aside, then, these assumptions, which proceed from incorrect or insufficient information, we may now refer to a consideration of the utmost importance, and which Mr. Croll himself, though he adduces it only in aid of the astronomical theory of glacial periods, has treated in so masterly a manner, as

[1] Von Wœickoff has very strongly put these principles in a Review of Croll's recent book, "Climate and Cosmology"; *American Journal of Science*, March, 1886.

really to give it the first place as an efficient cause. This is the varying distribution of ocean currents, in connection with the differences in the elevation and distribution of land. The great equatorial current, produced by the action of the solar heat on the atmosphere and the water, along with the earth's rotation, is thrown, by opposing continental shores, northward into the Atlantic and Pacific in the Gulf Stream and Japan current, giving us a hot-water apparatus which effectually raises the temperature of the whole northern hemisphere, and especially of the western sides of the continents. Mr. Croll imagined that if his astronomical causes could, to ever so small an extent, intensify the action of these currents, or their determination to the north, we should have a period of warmth, while a similar advantage given to the southern hemisphere would produce a glacial age in the north. But this requires us to assume what ought to be proved; namely, that the position of aphelion, and the increase or decrease of eccentricity, would actually so swing the equatorial current to the north or south. It further requires us to assume—and this is the most important defect of the theory — that no change occurs in the distribution of land and water; because any important change of this kind might obviously exert a dominant influence on the currents. Let us take two examples in illustration of this.

At the present time the warm water thrown into the North Atlantic, co-operating with the prevalent westerly winds, not only increases the temperature of its whole waters, but gives an exceptionally mild climate to western Europe. Still the countervailing influence of the Arctic currents and the Greenland ice, is sufficient to permit numerous icebergs to remain unmelted on the coast of Labrador and Newfoundland throughout the summer. Some of the bergs which creep down to the mouth of the Strait of Belle-Isle, in the latitude of the south of England, actually remain unmelted till the snows of a succeeding winter fall upon them. Now let us suppose that a subsidence of land

in tropical America were to allow the equatorial current to pass through into the Pacific. The effect would at once be to reduce the temperature of Norway and Britain to that of Greenland and Labrador at present, while the latter countries would themselves become colder. The northern ice, drifting down into the Atlantic, would not, as now, be melted rapidly by the warm water which it meets in the Gulf Stream. Much larger quantities of it would remain undissolved in summer, and thus an accumulation of permanent ice would take place, along the American coast at first, but probably at length even on the European side. This would still further chill the atmosphere, glaciers would be established on all the mountains of temperate Europe and America, the summer would be kept cold by melting ice and snow, and at length all eastern America and Europe might become uninhabitable, except by Arctic animals and plants, as far south as perhaps 40° of north latitude. This would be simply a return of the glacial age. I have assumed only one geographical change; but other and more complex changes of subsidence and elevation might take place, with effects on climate still more decisive.[1]

We may suppose an opposite case. The high plateau of Greenland might subside, or be reduced in height, and the opening of Baffin's Bay might be closed. At the same time the interior plain of America might be depressed, so that, as we know to have been the case in the Cretaceous period, the warm waters of the Mexican gulf might circulate as far north as the basins of the present great American lakes. In these circumstances there would be an immense diminution of the sources of floating ice, and a correspondingly vast increase in the surface of warm water. The effects would be to enable a

[1] According to Bonney, the west coast of Wales is about 12° above the average for its latitude, and if reduced to 12° below the average, its mountains would have large glaciers. So near is England even now to a glacial age.

temperate flora to subsist in Greenland, and to bring all the present temperate regions of Europe and America into a condition of subtropical verdure.

It is only necessary to add that we actually know that changes not dissimilar from those above sketched have really occurred in comparatively recent geological times, to enable us to perceive that we can dispense with all other causes of change of climate, though admitting that some of them may have occupied a secondary place. This will give us, in dealing with the distribution of life, the great advantage of not being tied up to definite astronomical cycles of glaciation, which do not well agree with the geological facts, and of correlating elevation and subsidence of the land with changes of climate affecting living beings. It will, however, be necessary, as Wallace well insists, that we shall hold to a certain fixity of the continents in their position, notwithstanding the submergences and emergences which they have experienced.

Sir Charles Lyell, more than forty years ago, published in his "Principles of Geology" two imaginary maps, which illustrate the extreme effects of various distribution of land and water. In one, all the continental masses are grouped around the equator. In the other they are all placed around the poles, leaving an open equatorial ocean. In the one case the whole of the land and its inhabitants would enjoy a perpetual summer, and scarcely any ice could exist in the sea. In the other, the whole of the land would be subjected to an Arctic climate, and it would give off immense quantities of ice to cool the ocean. Sir Charles remarks on the present apparently capricious distribution of land and water, the greater part being in the northern hemisphere, and, in this, placed in a very unequal manner. But Lyell did not suppose that any such distribution as that represented in his maps had actually occurred, though this supposition has been sometimes attributed to him. He merely put what he regarded as an extreme case to illustrate what

might occur under conditions less exaggerated. Sir Charles, like all other thoughtful geologists, was well aware of the general fixity of the areas of the continents, though with great modifications in the matter of submergences and of land conditions. The union, indeed, of these two great principles of fixity and diversity of the continents lies at the foundation of theoretical geology.

We can now more precisely indicate this than was possible when Lyell produced his "Principles," and can reproduce the conditions of our continents in even the more ancient periods of their history. An example of this may be given from the American continent, which is more simple in its arrangements than the double continent of Eurasia. Take, for instance, the early Devonian or Erian period, in which the magnificent flora of that age, the earliest certainly known to us, made its appearance. Imagine the whole interior plain of North America submerged, so that the continent is reduced to two strips on the east and west, connected by a belt of Laurentian land on the north. In the great mediterranean sea thus produced, the tepid water of the equatorial current was circulated, and it swarmed with corals, of which we know no less than 150 species, and with other forms of life appropriate to warm seas. On the islands and coasts of this sea was introduced the Erian flora, appearing first in the north, and with that vitality and colonizing power of which, as Hooker has well shown, the Scandinavian flora is the best modern type, spreading itself to the south. A very similar distribution of land and water in the Cretaceous age gave a warm and equable climate in those portions of North America not submerged, and coincided with the appearance of the multitude of broad-leaved trees of modern types which appeared in the middle Cretaceous, and prepared the way for the mammalian life of the Eocene.

We have in America ancient periods of cold as well as of warmth. I have elsewhere referred to the boulder conglomer-

ates of the Huronian, of the early Lower Silurian, and of the Millstone grit period of the Carboniferous; but I have not ventured to affirm that either of these periods was comparable in its cold with the later glacial age, still less with that imaginary age of continental glaciation, assumed by the more extreme theorists. We know that these ancient conglomerates were produced by floating ice, and this at periods when in areas not very remote, temperate floras and faunas could flourish. The glacial periods of our old continent occurred in times when the surface of the submerged land was opened up to the northern currents drifting over it mud and sand and stones, and rendering nugatory, in so far, at least, as the bottom of the sea was concerned, the effects of the superficial warm streams. Some of these beds are also peculiar to the eastern margin of the continent, and indicate ice drift along the Atlantic coast much as at present, while conditions of greater warmth existed in the interior. Even in the more recent glacial age, while the mountains were covered with snow, and the low lands submerged under a sea laden with ice, there were interior tracts in somewhat high latitudes of America in which hardy forest trees and herbaceous plants flourished abundantly, and these were by no means exceptional "interglacial" periods. Thus we can prove that from the remote Huronian period to the Tertiary, the American land occupied the same position as at present, and that its changes were merely changes of relative level, as compared with the sea; but which so influenced the ocean currents as to cause great vicissitudes of climate.

Uniformitarian geologists have recently been taunted with a willingness to assume great and frequent elevations and submergences of continents, as if this were contrary to their principle. But rational uniformitarianism allows us to use any cause of whose operation in the past there is good geological evidence, and Lyell himself was perfectly aware of this.

While no geologists can fail to appreciate the evidence of

the power of geographical change in affecting climatal change, and the fact that such change has occurred at various geological periods, there are some, and especially those who take extreme views as to the latest period of cold climate, who doubt its sufficiency to account for all the phenomena observed. It is instructive, however, to notice that some of the ablest of these, in default of other probable causes, are driven to fall back either on agencies of a wholly improbable character, or to give up the problem as insoluble. Two recent examples of this deserve citation.

The late Dr. Newmayr, of Vienna, a veteran physical geographer, in an able discussion of the climates of past ages, one of his last scientific papers, has fallen back on the hypothesis of a change in the position of the poles.[1] His failure to account for ancient climates by other causes evidently, however, depends on an inadequate conception of the effects of geographical changes, along with serious misconceptions as to the distribution of plants and the characters of vegetation at different periods. These points we shall have to discuss in subsequent pages.

In an address before the American Association, in 1886, Dr. Chamberlain, one of the ablest American authorities on the Glacial period, makes the following remarks as to the causes of the Pleistocene cold :—

"If we turn to the broader speculations respecting the origin of the Glacial epoch, we find our wealth little increased. We have on hand practically the same old stock of hypotheses, all badly damaged by the deluge of recent facts. The earlier theory of northern elevation has been rendered practically valueless; and the various astronomical hypotheses seem to be the worse for the increased knowledge of the distribution of the ancient ice sheet. Even the ingenious theory of Croll

[1] *Society for Dissemination of Natural Science.* Vienna, January, 1889.

becomes increasingly unsatisfactory as the phenomena are developed into fuller appreciation. The more we consider the asymmetry of the ice distribution in latitude and longitude, and its disparity in elevation, the more difficult it becomes to explain the phenomena upon any astronomical basis. If we were at liberty to disregard the considerations forced upon us by physicists and astronomers, and permit ourselves simply to follow freely the apparent leadings of the phenomena, it appears at this hour as though we should be led upon an old and forbidden trail,—the hypothesis of a wandering pole. It is admitted that there is a *vera causa* in elevations and depressions of the earth's crust, but it is held inadequate. It is admitted that the apparent changes of latitude shown by the determinations of European and American observatories are remarkable, but their trustworthiness is challenged. Were there no barriers against free hypotheses in this direction, glacial phenomena could apparently find adequate explanation; but debarred—as we doubtless should consider ourselves to be at present—from this resource, our hypotheses remain inharmonious with the facts, and the riddle remains unsolved."

It should be observed here that the unsolved "riddle" is that of a continental ice sheet. This, as we have already seen, is probably insoluble in any way, but fortunately needs no solution, being merely imaginary. If we adopt a moderate view as to the actual conditions of the Pleistocene, the geographical theory will be found quite sufficient to account for the facts.

Let it be observed here also, in connection with the above thoughtful and frank avowal of one of the ablest of American glacialists, that the geographical theory provides for that "asymmetry" or irregular distribution of glacial deposits to which he refers; since, at every stage of continental elevation and depression, there must have been local changes of circumstances; and the same inequality of temperature in identical

latitudes which we observe at present must have existed, probably in a greater degree, in the Glacial age.

The sufficiency of the Lyellian theory to account for the facts, in so far as plants are concerned, may, indeed, be inferred from the course of the isothermal lines at present. The south end of Greenland is on the latitude of Christiania, in Norway, on the one hand, and of Fort Liard, in the Peace River region, on the other; and while Greenland is clad in ice and snow, wheat and other grains, and the ordinary trees of temperate climates, grow at the latter places. It is evident, therefore, that only exceptionally unfavourable circumstances prevent the Greenland area from still possessing a temperate flora, and these unfavourable circumstances possibly tell even on the localities with which we have compared it. Further, the mouth of the McKenzie River is in the same latitude with Disco, near which are some of the most celebrated localities of fossil Cretaceous and Tertiary plants. Yet the mouth of the McKenzie River enjoys a much more favourable climate, and has a much more abundant flora than Disco. If North Greenland were submerged, and low land reaching to the south terminated at Disco, and if from any cause either the cold currents of Baffin's Bay were arrested, or additional warm water thrown into the North Atlantic by the Gulf Stream, there is nothing to prevent a mean temperature of 45° Fahrenheit from prevailing at Disco; and the estimate ordinarily formed of the requirements of its extinct floras is 50°, which is probably above, rather than below, the actual temperature required.

We thus know that the present distribution of land and water greatly influences climate, more especially by affecting that of the ocean currents and of the winds, and by the different action of land as compared with water in the reception and radiation of heat. The present distribution of land gives a large predominance to the Arctic and sub-Arctic regions,

as compared with the equatorial and with the Antarctic; and we might readily imagine other distributions that would give very different results. But this is not an imaginary case, for we can to some extent restore, on geological grounds, the ancient geography of large regions, and can show that it has been very different from that prevailing at present. We know also that, while the forms and positions of the great continents have been fixed from a very early date, they have experienced many great submergences and re-elevations, and that these have occurred in somewhat regular sequence, as evidenced by the cyclical alternations of organic limestones and earthy sediments in the successive great geological periods, each of which, as may be seen in any geological text book, presents a dip of the continental plateaus, with subsequent elevation, as if the land was subject to a series of regular pulsations.[1]

Finally, the Lyellian theory tends to abate the tendency to imagine portentous and impossible climatal changes; and it inclines geologists to give more attention to the connection of palæo-geography with changes in the life history of the earth.

REFERENCES:—"Acadian Geology," 1st ed., 1855; 4th ed., 1892. Icebergs of Belle-Isle, and Glaciers of Mont Blanc, *Canadian Naturalist*, 1865. "Notes on Pleistocene of Canada," Montreal, 1871. Papers at various dates in the *Canadian Naturalist* and *Canadian Record of Science*. "The Ice Age in Canada," Montreal, 1892. Canadian Pleistocene, *London Geological Magazine*, March, 1883. Flora of the Pleistocene, Dawson and Penhallow. *Bulletin of Geological Society of America*, vol. i., 1890, p. 311.

[1] See "Acadian Geology"—Introduction to the Carboniferous System.

THE DISTRIBUTION OF ANIMALS AND PLANTS AS RELATED TO GEOGRAPHICAL AND GEOLOGICAL CHANGES.

DEDICATED TO THE MEMORY OF MY LATE FRIEND,

MR. GWYN JEFFRIES,

WHO SO ABLY INVESTIGATED THE DISTRIBUTION

OF OCEANIC MOLLUSKA,

MORE ESPECIALLY IN THE NORTH ATLANTIC.

Changes of Climate and of Land and Water with Reference to Distribution of Life — Regions of the Continents—Insular Faunas and Floras—Their History—Applications to Geology and to Man—Geological Time—Theories of Introduction and Migration



VERTEBRATA.

PALEOZOIC	MESOZOIC	KAINOZOIC	MODERN

1 3 4 6 5 2

INVERTEBRATA.

PALEOZOIC	MESOZOIC	KAINOZOIC	MODERN

4 1 6 3 5 2

DISTRIBUTION OF ANIMALS IN TIME. (p. 420.)

Vertebrata.—1, Ganoid Fishes; 2, Teliort Fishes; 3, Batrachians; 4, Reptiles; 5, Birds; 6, Mammals.

Invertebrata.—1, Trilobites, etc.; 2, Worms; 3, Bivalve and Univalve Shellfishes; 4, Nautiloid Shellfishes; 5, Cuttlefishes; 6, Brachiopods.

It will be noticed that Nos. 2 and 5 in the first table, and 3 and 5 in the second, follow a different order of curve from the others, indicating their exceptional culmination in modern times.

CHAPTER XV.

THE DISTRIBUTION OF ANIMALS AND PLANTS AS RELATED TO GEOGRAPHICAL AND GEOLOGICAL CHANGES.

ALL are now agreed that to explain the extraordinary and often apparently anomalous distribution of animals and plants over the surface of the earth, and the occurrence of like forms in very distant localities, and even on islands separated by vast stretches of ocean from one another and from the continents, we must invoke the aid of geology. We must have reference to those changes of climate and of elevation which have occurred in the more recent periods of the earth's history, and must carry with us the idea, at first not apparently very reasonable, that living beings have existed much longer than many of the lands which they inhabit, or at least than the present state of those lands in reference to isolation or continental connection. To what extent we may further require to call in the aid of varietal or specific modification to explain the facts, may be more doubtful; and I think we shall find that a larger acquaintance with geological truths would enable us to dispense with the aid of hypotheses of evolution, at least in so far as the local establishment of new generic and specific types is concerned.

One of the most remarkable and startling results of geological investigation, and one which must be accepted as an established fact, independently of all theoretical explanations, is that the earth has experienced enormous revolutions of

climate within comparatively late periods, and since the date of the introduction of many existing species of animals and plants. To this great truth, in some of its bearings, I have endeavoured to direct attention in the previous articles. In the present case it will be necessary to consider these vicissitudes in their more general aspects, and with some reference to their effects on the distribution of living beings.

The modern or human period of geology, that in which man and his contemporaries are certainly known to have inhabited the earth, was immediately preceded by an age of climatal refrigeration known as the Glacial or Ice age. This was further characterized not only by a prevalence of cold, unexampled so far as known either before or since, but by immense changes of the relative levels of sea and land, amounting, in some cases, at least, to several thousands of feet. The occurrence of these changes is clearly proved by the undoubted traces of the action of ice, whether land ice or floating ice, on all parts of our continents, half way to the equator, and by the occurrence of sea terraces and modern marine shells at high levels on mountains and table-lands. Perhaps we scarcely realize as we should the stupendous character of the changes involved in the driftage of heavy ice over our continents as far south as the latitude of 40°, in the deposit of boulders on hills several thousands of feet in height, and in the occurrence of shells of species still living in the sea, in beds raised to more than twelve hundred feet above its present level. Yet such changes must have occurred in the latest geological period immediately preceding that in which we live. Proceeding farther back in geological time, we find the still more extraordinary fact that in the middle and earlier Tertiary the northern hemisphere enjoyed a climate so much more mild than that which now prevails, that plants at present confined to temperate latitudes could flourish in

Greenland and Spitzbergen.[1] The age in which we live is thus one of mediocrity, attaining neither to the Arctic rigour of the later Pleistocene, nor to the universal mildness of the preceding Miocene.

The causes of these changes of climate we have discussed elsewhere. It remains for .us now to consider the actual condition of our present continents, and the bearing of past conditions on the distribution of their living inhabitants.

In speaking of continents and islands, it may be as well to remark at the outset that all the land existing, or which probably has at any time existed, consists of islands great or small. It is all surrounded by the ocean. Two of the greater masses of land are, however, sufficiently extensive to be regarded as continents, and from their very extent and consequent permanence may be considered as the more special homes of the living beings of the land. Two other portions of land, Australia and the Antarctic polar continent, may be regarded either as smaller continents or large islands, but partake of insular rather than continental characters in their animals and plants. All the other portions of land are properly islands; but while these islands, and more especially those in mid-ocean, cannot be regarded as the original homes of many forms of life, we shall find that they have a special interest as the shelters and refuges of numerous very ancient and now decaying species.

The two great continents of America and Eurasia have been the most permanent portions of the land throughout geological time, some parts of them having always been above water, probably from the Laurentian age downward, though at various times they have been reduced to little more than groups of islands. On them, and more especially in their more northern

[1] As I have elsewhere shown, a warm climate in an Arctic region seems to have afforded the necessary conditions for the great colonizing floras of all geological periods.

parts, in which the long continuance of daylight in summer seems in warm periods to have been peculiarly favourable to the introduction of new vegetable and animal forms, and to the giving to them that vigour necessary for active colonization, have originated the greater number of the inhabitants of the land.

Regarded as portions of the earth's crust, the continents are areas in which the lateral thrust, caused by the secular con traction of the interior of the earth and unequal settlement of the crust, has ridged up and folded the rocks, producing mountain chains. This process began in the earliest geological periods, and has been repeated at long intervals, the original lines of folding guiding those formed in each new thrust proceeding from the broad oceanic areas. Along the ridges thus produced, and in the narrower spaces between them, the greater part of the sediment carried by water was laid down, thus producing plateaus in connection with the mountain-chains, while the weight of new sediments and the removal of matter from other areas by denudation, have been constantly producing local depression and elevation. The tendency of the ocean to be thrown toward the poles by the retardation of the earth's rotation, alternating with great collapses of the crust at the equator proceeding from the same cause, along with the secular cooling, have produced alternate submergence and emergence of these plateaus. This has been further complicated by the constant tendency of the Arctic and Antarctic currents, aided by ice, to drift solid materials, set free by the vast denuding action of frost, from the polar to the temperate regions, and by the further tendency of animal life to heap up calcareous accumulations under the warm waters of the tropical regions. All these changes, as already stated, have conspired to modify the directions of the great oceanic currents, and to produce vicissitudes of climate under which animals and plants have been subjected in geological time to

those migrations, extinctions, and renovations of which their fossil remains and present distribution afford evidence.

Still, it is true that throughout the whole of these great mutations, since the beginning of geological history, there seems never to have been any time when the ocean so regained its dominion as to produce a total extinction of land life; still less was there any time when the necessary conditions of all the various forms of marine life failed to be found; nor was there any climatal change so extreme as to banish any of the leading forms of life from the earth. To geologists it is not necessary to say that the conclusions sketched above are those that have been reached as the results of long and laborious investigation, and which have been illustrated and established by Lyell, Dana, Wallace,[1] and many other writers.[2] Let us now place beside them some facts as to the present distribution of life, and of the agencies which influence it.

Just as political geography sometimes presents boundaries not in accordance with the physical structure of countries, so the distribution of animals and plants shows many peculiar and unexpected features. Hence naturalists have divided the continents into what Sclater has called zoological regions, which are, so to speak, the great empires of animal life, divisible often by less prominent boundaries into provinces. In vegetable life similar boundaries may be drawn, more or less coincident with the zoological divisions. Zoologically, North America and Greenland may be regarded as one great region, the Nearctic, or new Arctic, the prefix not indicating that the animals are newer than those of the old world, which is by no means the case. South America constitutes another region—

[1] Wallace, "Geographical Distribution of Animals" and "Island Life." Second edition.

[2] The writer has endeavoured to popularize these great results of geology in his work, the "Story of the Earth." Ninth Edition. London, 1887. They are often overlooked by specialists, and by compilers of geological manuals.

the Neotropical. If now we turn to the greater Eurasian continent, with its two prolongations to the south in Africa and Australia, we shall find the whole northern portion, from the Atlantic to the Pacific, constituting one vast region of animal life, the Palearctic, which also includes Iceland and a strip across North Africa. Africa itself, with Madagascar, whose allegiance is, however, only partial, constitutes the Ethiopian region. India, Burmah, the south of China, and certain Asiatic islands form the Oriental region. Australia, New Guinea, and the Polynesian islands constitute the Australian region. All of these regions may in a geological point of view be considered as portions of old and permanent continental masses, which, though with movements of elevation and depression, have continued to exist for vast periods. Some of them, however, seem to have enjoyed greater immunity from causes of change than others, and present, accordingly, animals and plants having, geologically speaking, an antique aspect in comparison. In this sense the Australian province may be regarded as the oldest of all in the facies of its animal forms, since creatures exist there of genera and families which have very long ago become extinct everywhere else. Next in age to this should rank the Neotropical or South American region, which, like Australia, presents many low and archaic forms of animal life. The Ethiopian region stands next to it in this, the Oriental and Nearctic next, and last and most modern in its aspect is the great Palearctic region, to which man himself belongs, and the animals and plants of which vindicate their claims to youth by that aggressive and colonizing character already referred to, and which has enabled them to spread themselves widely over the other regions, even independently of the influence of man. On the other hand, the animals and plants of the Australian aud South American regions show no such colonizing tendency, and can scarcely maintain themselves against those of other regions when introduced among them.

Thus we have at once in these continental regions a great and suggestive example of the connection of geographical and geological distribution, the details of which are of the deepest interest, and have not yet been fully worked out. One great principle is, however, sufficiently established ; namely, that the northern regions have been the birthplace of new forms of land life, whence they have extended themselves to the south, while the comparative isolation and equable climate of the South American and Australian regions have enabled them to shelter and retain the old moribund tribes.

Those smaller portions of land separated from the continental masses, the islands properly so called, present, as might be expected, many peculiar features. Wallace divides them into two classes, though he admits that these pass into each other. Continental islands are those in the vicinity of continents. They consist of ancient as well as modern rock formations, and contain animals which indicate a former continental connection. Some of these are separated from the nearest mainland only by shallow seas or straits, and may be assumed to have become islands only in recent geological times. Others are divided from the nearest continent by very deep water, so that they have probably been longer severed from the mainland. These contain more peculiar assemblages of animals and plants than the islands of the former class. Oceanic islands are more remote from the continents. They consist mostly of rocks belonging to the modern geological periods, and contain no animals of those classes which can migrate only by land. Such islands may be assumed never to have been connected with any continent. The study of the indigenous population of these various classes of islands affords many curious and interesting results, which Wallace has collected with vast industry and care, and which, on the whole, he explains in a judicious manner and in accordance with the facts of geology. When, however, he maintains that

evolution of the Darwinian type is "the key to distribution," he departs widely from any basis of scientific fact. This becomes apparent when we consider the following results, which appear everywhere in the discussion of the various insular faunas and floras:—(1) None of these islands, however remote, can be affirmed to have been peopled by the spontaneous evolution of the higher animals or plants from lower forms. Their population is in every case not autochthonous, but derived. (2) Even in those which are most distant from the continents, and may be supposed to have been colonized in very ancient times, there is no evidence of any very important modification of their inhabitants. (3) While the facts point to the origin of most forms of terrestrial life in the Palearctic and Nearctic regions, they afford no information as to the manner or cause of their origination. In short, so far is evolution from being a key to distribution, that the whole question would become much more simple if this element were omitted altogether. A few examples may be useful to illustrate this, as well as the actual explanation of the phenomena afforded by legitimate science.

The Azores are situated in a warm temperate latitude about 900 miles west of Portugal, and separated from it by a sea 2,500 fathoms in depth. The islands themselves are almost wholly volcanic, and the oldest rocks known in them are of late Miocene age. There is no probability that these islands have ever been connected with Europe or Africa, nor is there at present any certainty that they have been joined to one another, or have formed part of any larger insular tract. In these islands there is only one indigenous mammal, a bat, which is identical with a European species, and no doubt reached the islands by flight. There is no indigenous reptile, amphibian, or fresh-water fish. Of birds there are, exclusive of waterfowl, which may be regarded as visitors, twenty-two land birds; but of these, four are regarded as merely accidental

stragglers, so that only eighteen are permanent residents. Of these birds fifteen are common European or African species, which must have flown to the islands, or have been drifted thither in storms. Of the remaining three, two are found also in Madeira and the Canaries, and therefore may reasonably be supposed to have been derived from Africa. One only is regarded as peculiar to the Azores, and this is a bullfinch, so nearly related to the European bullfinch that it may be regarded as merely a local variety. Wallace accounts for these facts by supposing that the Azores were depopulated by the cold of the Glacial age, and that all these birds have arrived since that time. There is, however, little probability in such a supposition. He further supposes that fresh supplies of stray birds from the mainland, arriving from time to time, have kept up the identity of the species. Instead of evolution assisting him, he has thus somewhat to strain the facts to agree with that hypothesis. Similar explanations are given for the still more remarkable fact that the land plants of the Azores are almost wholly identical with European and African forms. The insects and the land snails are, however, held to indicate the evolution of a certain number of new specific forms on the islands. The beetles number no less than 212 species, though nearly half of them are supposed to have been introduced by man. Of the whole number 175 are European, 19 are found in Madeira and the Canaries, 3 are American. Fourteen remain to be accounted for, though most of these are closely allied to European and other species; but a few are quite distinct from any elsewhere known. Wallace, however, very truly remarks that our knowledge of the continental beetles is not complete; that the species in question are small and obscure; that they may be survivors of the Glacial period, and may thus represent species now extinct on the mainland; and that for these reasons it may not be irrational to suppose that these peculiar insects either still inhabit, or did once inhabit, some

part of the continents, and may be portions of "ancient and widespread groups," once widely diffused, but now restricted to a few insular spots. Among the land snails, if anywhere, we should find evidence either of autochthonous evolution or of specific change. These animals have existed on the earth since the Carboniferous period, and, notwithstanding their proverbial slowness and sedentary habits, they have contrived to colonize every habitable spot of land on the globe—that is, unless in some of these places they have originated *de novo.* In the Azores there are sixty-nine species of land snails, of which no less than thirty-two, or nearly one-half, are peculiar, though nearly all are closely allied to European types. What, then, is the origin of these thirty-two species, admitting for the sake of argument that they are really distinct, and not merely varietal forms, though it is well known that in this group species are often unduly multiplied. Three suppositions are possible. (1) These snails may have originated in the islands themselves, either by creation or evolution from lower forms; say, from sea snails. (2) They may have been modified from modern continental species. (3) They may be unmodified descendants of species of Miocene or Pliocene age now existing on the continents only as fossils. As the islands appear to have existed since Miocene times, it is no more improbable that species of that or the Pliocene age should have found their way to them than that modern species should; and as we know only a fraction of the Tertiary species of Europe or Africa, it is not likely that we shall be able to identify all of these early visitors. Unfortunately no Miocene or Pliocene deposits holding remains of land snails are known in the Azores themselves, so that this kind of evidence fails us. In Madeira and Porto Santo, however, where there are numerous modern snails, there are Pliocene beds holding remains of these animals. In Madeira there are, according to Lyell, 36 Pliocene species, and in Porto Santo 35, and of these only eight

are extinct. Thus we can prove that many of the peculiar species of these islands have remained unchanged since Pliocene times. While differing from modern European shells, several of these species are very near to European Miocene species. Thus we seem to have evidence in the Madeira group, not of modification, but of unchanged survival of Tertiary species long since extinct in Europe. May we not infer that the same was the case in the Azores? These results are certainly very striking when we consider how long the Azores must have existed as islands, how very rarely animals, and especially pairs of animals, must have reached them, and how complete has been the isolation of these animals, and how peculiar the conditions to which they have been subjected in their island retreat.

Other oceanic islands present great varieties of conditions, but leading to similar conclusions. Some, as the Bermudas, seem to have been settled in very modern times with animals and plants nearly all identical with those of neighbouring countries, though even here it would appear that there are some indigenous species which would indicate a greater age or more extended lands, now submerged.[1] Others, like St. Helena, are occupied apparently with old settlers, which may have come to them in early Tertiary, or even in Secondary periods, which have long since become extinct on the continents, and whose nearest analogues are now widely scattered over the world. Islands are therefore places of survival of old species—special preserves for forms of life lost to the continents. One of the most curious of these is Celebes, which seems to be a surviving fragment of Miocene Asia, which, though so near to that continent, has been sufficiently isolated to preserve its old popula-

[1] Heilprin mentions eleven marine mollusks supposed to be peculiar to the islands, and eight species of land shells, as well as a few Crustaceans hitherto found only in the Pacific. The comparisons are, however, admitted to be incomplete.

tion during all the vast lapse of time between the middle Tertiary and the present period. This is a fact which gives to the oceanic islands the greatest geological interest, and induces us to look into their actual fauna and flora for the representatives of species known on the mainland only as fossils. It is thus that we look to the marsupials of Australia as the nearest analogues of those of the Jurassic of Europe, and that we find in the strange Barramunda (*ceratodus*) of its rivers the only survivor of a group of fishes once widely distributed, but which has long since perished elsewhere.

Perhaps one of the most interesting examples of this is furnished by the Galapagos Islands, an example the more remarkable that no one who has read in Darwin's fascinating "Journal" the description of these islands, can have failed to perceive that the peculiarities of this strange Archipelago must have been prominent among the facts which first planted in his mind the germ of that theory of the origin of species which has since grown to such gigantic dimensions. It is curious also to reflect that had the bearing of geological history on the facts of distribution been as well known forty years ago as it is now, the reasoning of the great naturalist on this and similar cases might have taken an entirely different direction.

The Galapagos are placed exactly on the equator, and therefore out of reach of even the suspicion of having been visited by the glacial cold, though from their isolation in the ocean, and the effects of the currents flowing along the American coast, their climate is not extremely hot. They are 600 miles west of South America, and the separating ocean is in some parts 3,000 fathoms deep. The largest of the islands is 75 miles in length, and some of the hills attain an elevation of about 4,000 feet, so that there are considerable varieties of station and climate. So far as is known they are wholly volcanic, and they may be regarded as the summits of submerged mountains not unlike in structure to the Andes of the main-

land. Their exact geological age is unknown, but there is no improbability in supposing that they may have existed with more or less of extension since the Secondary or Mesozoic period. In any case their fauna is in some respects a survival of that age. Lyell has truly remarked, "In the fauna of the Galapagos Islands we have a state of things very analogous to that of the Secondary period."

Like other oceanic islands, the Galapagos have no indigenous mammals, with the doubtful exception of a South American mouse; but, unlike most others, they are rich in reptiles. At the head of these stand several species of gigantic tortoises. This group of animals, so far as known, commenced its existence in the Eocene Tertiary; and in this and the Miocene period still more gigantic species existed on the continents. It has been supposed that at some such early date they reached the Galapagos from South America. Another group of Galapagan reptiles, perhaps still more remarkable, is that of iguana-like lizards of the genus *Amblyrhyncus*, which are vegetable feeders,—one of them browsing on marine weeds. They recall the great iguana-like reptiles of the European Wealden, and stand remote from all modern types. There are also snakes of two species, but these are South American forms, and may have drifted to the islands in comparatively recent times on floating trees. The birds are a curious assemblage. A few are common American species, like the rice bird. Others are quaint and peculiar creatures, allied to South American birds, but probably representing forms long since extinct on the continent. The bird fauna, as Wallace remarks, indicates that some of these animals are old residents, others more recent arrivals; and it is probable that they have arrived at various times since the early Tertiary. He assumes that the earlier arrivals have been modified in the islands "into a variety of distinct types"; but the only evidence of this is that some of the species are closely related to each other. It is more likely

that they represent to our modern eyes the unmodified descendants of continental birds of the early Tertiary. Darwin remarks that they are remarkably sombre in colouring for equatorial birds; but perhaps their ancestors came from a cooler climate, and have not been able to don a tropical garb; or perhaps they belong to a far-back age, when the vegetable kingdom also was less rich in colouring than it is at present, and the birds were in harmony with it. This, indeed, seems still to be the character of the Galapagos plants, which Darwin says have "a wretched, weedy appearance," without gay flowers, though later visitors have expressed a more favourable opinion.

These plants are in themselves very remarkable, for they are largely peculiar species, and are in many cases confined to particular islands, having apparently been unable to cross from one island to another, though in some way able to reach the group. The explanation is that they resemble North American plants, and came to the Galapagos at a time when a wide strait separated North and South America, allowing the equatorial current to pass through, and drift plants to the Galapagos, where they have been imprisoned ever since. This was probably in Miocene times, and when we know more of the Miocene flora of the southern part of North America we may hope to recover some of the ancestors of the Galapagos plants. In the meantime their probable origin and antiquity, as stated by Wallace, render unnecessary any hypothesis of modification.

Before leaving this subject, it is proper to observe that on the continents themselves there are many remarkable cases of isolation of species, which help us better to understand the conditions of insular areas. The "variable hare" of the Scottish highlands, and of the extreme north of Europe, appears again in the Alps, the Pyrenees, and the Caucasus, being in these mountains separated by a thousand miles of apparently impassable country from its northern haunts. It no doubt extended itself over the intervening plains at a time when Europe

was colder than at present. Another curious case is that of the marsh-tit of Europe. This little bird is found throughout south-western Europe. It reappears in China, but is not known anywhere between. In Siberia and northern Europe there is, however, a species or distinct race which connects these isolated patches. In this case, if the Siberian species is truly distinct, we have a remarkable case of isolation and of the permanence of identical characters for a long time; for in that case this bird must be a survivor of the Pliocene or Miocene time. On the other hand, if, as is perhaps more likely, the marsh-tit is only a local variety of the Siberian species, we have an illustration of the local recurrence of this form when the conditions are favourable, even though separated by a great space and long time.

The study of fossils gives us the true meaning of such facts, and causes us to cease to wonder at any case of local repetition of species, however widely separated. The "big trees" of California constitute a remarkable example. There are at present two very distinct species of these trees, both found only in limited areas of the western part of North America. Fossil trees of the same genus (*Sequoia*) occur as far back as the Cretaceous age; but in this age ten or more species are known. Nor are they confined to America, but occur in various parts of the Eurasian continent as well. Two of the Lower Cretaceous species are so near to the two modern ones that even an unbeliever in evolution may suppose them to be possible ancestors; the remaining eight are distinct, but some of them intermediate in their characters. In the Tertiary period, intervening between the Cretaceous and the modern, fourteen species of *Sequoia* are believed to have been recognised, and they appear to have existed abundantly all over the northern hemisphere. Thus we know that these remarkable Californian giants are the last remnant of a once widely distributed genus, originating, as far as known, in the Cretaceous age.

Now had a grove of *Sequoias*, however small, survived anywhere in Europe or Asia, and had we no knowledge of the fossil forms, we might have been quite at a loss to account for their peculiar distribution. The fossil remains of the Tertiary rocks, both animal and vegetable, present us with many instances of this kind.

The discussion of the distribution of animals and plants, when carried on in the light of geology, raises many interesting questions as to time, which we have already glanced at, but which deserve a little more attention. As to the vast duration of geological time all geologists are agreed. It is, however, now well understood that science sets certain limits to the time at our disposal. Edward Forbes humorously defined a geologist to be "an amiable enthusiast who is content if allowed to appropriate as much as he pleases of that which other men value least, namely, past time"; but now even the geologist is obliged to be content with a limited quantity of this commodity.

The well-known estimate of Lord Kelvin gave one hundred millions of years as the probable time necessary for the change of the earth from the condition of a molten mass to that which we now see. On this estimate we might fairly have assumed fifty millions of years as covering the time from the Laurentian age to the modern period. The great physicist has, however, after allowing us thus much credit in the bank of time, "suddenly put up the shutters and declared a dividend of less than four shillings in the pound."[1] In other words, he has reduced the time at our disposal to twenty millions of years. Other physicists, reasoning on the constitution of the sun, agree with this latter estimate, and affirm that "twenty millions of years ago the earth was enveloped in the fiery atmosphere of the sun."[2] Geology itself has attempted an independent cal-

[1] Bonney, Address before British Association, 1888.

[2] Newcomb, Helmholtz, Tait, etc.

culation based on the wearing down of our continents, which appears to proceed at the rate of about a foot in four or five thousand years, and on the time required to deposit the sediments of the several geological formations, estimated at about 70,000 feet in thickness. These calculations would give us, say, eighty-six millions of years since the earth began to have a solid crust, which would, like Lord Kelvin's earlier estimate, give us nearly fifty millions of years for the geological time since the introduction of life. The details of the several estimates made it would be tedious and unprofitable to enter into, but I may state as my own conclusion, that the modern rates of denudation and deposit must be taken as far below the average, and that perhaps the estimate stated by Wallace on data supplied by Houghton, namely, twenty-eight millions, may be not far from the truth, though perhaps admitting of considerable abatement.

This reduced estimate of geological time would still give scope enough for the distribution of animals and plants, but it will scarcely give that required by certain prevalent theories of evolution. When Darwin says, "If the theory (of natural selection) be true, it is indisputable that before the lowest Cambrian stratum was deposited long periods elapsed, as long as, or probably far longer than, the whole interval from the Cambrian to the present day," he makes a demand which geology cannot supply; for independently of our ignorance of any formations or fossils, except those included in the Archæan, to represent this vast succession of life, the time required would push us back into a molten state of the planet. This difficulty is akin to that which meets us with reference to the introduction of many and highly specialized mammals in the Eocene, or of the forests of modern type in the Cretaceous. To account for the origin of these by slow and gradual evolution requires us to push these forms of life so far back into formations which afford no trace of them, but, on the contrary,

contain other creatures that appear to be exclusive of them, that our faith in the theory fails. The only theory of evolution which seems to meet this difficulty is that advanced by Mivart, Leconte, and Saporta, of "critical periods," or periods of rapid introduction of new species alternating with others of comparative inaction. This would much better accord with the apparently rapid introduction of many new forms of life over wide regions at the same period. It would also approach somewhat near, in its manner of stating the problem to be solved, to the theory of "creation by law" as held by the Duke of Argyll, or to what may be regarded as "mediate creation," proceeding in a regular and definite manner, but under laws and forces as yet very imperfectly known, throughout geological time.

It seems singular, in view of the facts of palæontology, that evolutionists of the Darwinian school are so wedded to the idea of one introduction only of each form of life, and its subsequent division by variation into different species, as it progressively spreads itself over the globe, or is subjected to different external conditions. It is evident that a little further and very natural extension of their hypothesis would enable them to get rid of many difficulties of time and space. For example, certain Millipedes and Batrachians are first known in the coal formation, and this not in one locality only, but in different and widely separated regions. If they took beginning in one place, and spread themselves gradually over the world, this must have required a vast lapse of time—more than we can suppose probable. But if, in the coal-formation age, a worm could anywhere change into a Millipede, or a fish into a Batrachian, why might this not have occurred in many places at once? Again, if the oldest known land snails occur in the coal formation, and we find no more specimens till a much later period, why is it necessary to suppose that these creatures existed in the intervening time, and that the later

species are the descendants of the earlier? Might not the process have been repeated again and again, so as to give animals of this kind to widely separated areas and successive periods without the slow and precarious methods of continuous evolution and migration? This apparent inconsistency strikes one constantly in the study of discussions of the theory of derivation in connection with geographical and geological distribution. We constantly find the believers in derivation laboriously devising expedients for the migration of animals and plants to the most unlikely places, when it would seem that they might just as well have originated in those places by direct evolution from lower forms. Those who believe in a separate centre of creation for each species must of course invoke all geological and geographical possibilities for the dispersion of animals and plants; but surely the evolutionist, if he has faith in his theory, might take a more easy and obvious method, especially when in any case he is under the necessity of demanding a great lapse of time. That he does not adopt this method perhaps implies a latent suspicion that he must not repeat his miracle too often. He also perceives that if repeated and unlimited evolution of similar forms had actually occurred, there could have remained little specific distinctness, and the present rarity of connecting links would not have occurred. Further, a new difficulty would have sprung up in the geographical and geological relations of species and genera, which would then have assumed too much of the aspect of a preconceived plan. It is only fair to a well-known and somewhat extreme European evolutionist, Karl Vogt, to state that he launches boldly into the ocean of multiple evolution, not fearing to hold that identical species of mollusks have been separately evolved in separate Swiss lakes, and that the horse has been separately evolved in America and in Europe, in the former along a line beginning with *Eohippus*, and in the latter along an entirely separate line,

commencing with *Paleotherium*. The serious complications resulting from such admissions are evident, but Vogt deserves credit for faith and consistency beyond those of his teachers.

With reference to the actual distribution of species, the question of time becomes most important when applied to the Glacial period, since it is obvious that much of the present distribution must have been caused, or greatly modified, by that event. The astronomical theory would place the close of the Glacial age as far back as 70,000 or 80,000 years ago. But we have already seen in the chapter on that period that geological facts bring its close to only from 10,000 to 7,000 years before our time. If we adopt the shorter estimates afforded by these facts, it will follow that the submergences and emergences of land in the Glacial ages were more rapid than has hitherto been supposed, and that this would react on our estimate of time by giving facilities for more rapid denudation and deposition. Such results would greatly shorten the duration assignable to the human period. They would render it less remarkable that no new species of animals seem to have been introduced since the Glacial age, that many insular faunas belong to far earlier times, and that no changes even leading to the production of well-marked varieties have occurred in the post-glacial or modern age.

In conclusion, does all this array of fact and reasoning bring us any nearer to the comprehension of that "mystery of mysteries," the origin and succession of life? It certainly does not enable us to point to any species, and to say precisely here, at this time and thus it orginated. If we adopt the theory of evolution, the facts seem to restrict us to that form of it which admits paroxysmal or intermittent introduction of species, depending on the concurrence of conditions favourable to the action of the power, whatever it may be, which produces new organisms. Nor is there anything in the facts of distribution to invalidate the belief in creation, according to

definite laws, if that really differs in its nature from certain forms of the hypothesis of evolution. We have also learned that, time being given, animals and plants manifest wonderful powers of migration, that they can vary within considerable limits without ceasing to be practically the same species, and that under certain conditions they can endure far longer in some places than in others. We also see evidence that it is not on limited islands, but on the continents, that land animals and plants have originated, and that swarms of new and vigorous species have issued from the more northern regions in successive periods of favourable Arctic climate. The last of these new swarms or "centres of creation," that with which man himself is more closely connected, belongs to the Palearctic region. We have already seen that in every geological period, when the submerged continental plateaus were pervaded by the warm equatorial waters, multitudes of new marine species appear. In times when, on the contrary, the colder Arctic currents poured over these submerged surfaces, carrying mud and stones, great extinction took place, but certain northern forms of life swarmed abundantly, and when elevation took place, marine species became extinct or were forced to migrate. Everywhere and at all times multiplication of species was promoted by facilities for expansion. The great limestones of our continents, full of corals and shells of new species, belong to times when the ocean spread itself over the continental plateaus, affording wide, untenanted areas of warm and shallow water. The introduction of new faunas and floras on the land belongs to times when vast supplies of food for plants and animals and favourable conditions of existence were afforded by the emergence of new lands possessing fertile soils and abundantly supplied with light, heat, and moisture. Thus geological and geographical facts concur with ordinary observation and experience in reference to varietal forms, in testifying that it is not mere struggle for

existence, but facilities for easy existence and rapid extension, that afford the conditions necessary for new and advanced forms of life. These considerations do not, of course, reach to the first cause of the introduction of species, nor even to the precise mode in which this may have acted in any particular case; but perhaps we cannot fully attain to this by any process of inductive inquiry. The study of geographical distribution, therefore, does not enable us to solve the question of the origin of specific types, but, on the contrary, points to marvellous capacities for migration and a wonderful tenacity of life in species. In these respects, however, it is a study full of interest, and in nothing more so than in the evidence which it affords of the practically infinite provisions made for the peopling of every spot of land or sea with creatures fitted to flourish and enjoy life therein, and to carry on the great and progressive plan of the Creator.

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ALPINE AND ARCTIC PLANTS IN CONNECTION WITH GEOLOGICAL HISTORY.

DEDICATED TO THE MEMORY OF

DR. ASA GRAY,

THE GREATEST AND MOST PHILOSOPHICAL EXPONENT

OF AMERICAN BOTANY.

A Botanico - Geological Excursion in the White Mountains—Distribution and Migrations of Alpine Plants—Relations to the Later Geological Changes—Bearing on the Vegetation of Earlier Times





Mount Washington, from Tuckerman's Ravine. (p. 426.)
(After Filmer, in King's "White Hills.")

CHAPTER XVI.

ALPINE AND ARCTIC PLANTS IN CONNECTION WITH GEOLOGICAL HISTORY.

THE group of the White Mountains is the culminating point of the northern division of the great Appalachian range, extending from Tennessee to Gaspé in a south-west and north-east direction, and constituting the breast bone of the North American continent. This great ridge or succession of ridges has its highest peaks near its southern extremity, in the Black Mountains; but these are little higher than their northern rivals, which at least hold the undisputed distinction of being the highest hills in north-eastern America. As Guyot[1] has well remarked, the White Mountains do not occur in the general line of the chain, but rather on its eastern side. The central point of the range, represented by the Green Mountains and their continuation, describes a great curve from Gaspé to the valley of the Hudson, and opposite the middle of the concave side of this curved line towers the almost isolated group of the White Hills. On the other side is the narrow valley of Lake Champlain, and beyond this the great isolated mass of the Adirondack Mountains, nearly approaching in the altitude of their highest peaks, and greatly exceeding in their geological age, the opposite White Mountain group. The Appalachian range is thus, in this part of its course, supported on either side by outliers higher than itself. The dense grouping of mountains in this region is due to the resistance offered by the old Adiron-

[1] *Silliman's Journal.*

dack mass to the westward thrust of the Atlantic and the subsequent piling up against this mass of the ridges of palæozoic sediments. Southward of this the Atlantic thrust has driven these ridges back in a great bend to the westward.

My present purpose is not to give a general geographical or geological sketch of the White Mountains, but to direct attention to the vegetation which clothes their summits, and its relation to the history of the mountains themselves. For this purpose I may first shortly describe the appearances presented in ascending the highest of them, Mount Washington, and then turn to the special points to which these notes relate.

In approaching Mount Washington by the Grand Trunk Railway, the traveller has ascended from the valley of the St. Lawrence to a height of 802 feet at the Alpine House at Gorham. Thence, in a distance of about eight miles along the bank of the Peabody River, to the Glen House, he ascends to the elevation of 1,632 feet above the sea; and it is here, or immediately opposite the Glen House, that the actual ascent begins. The distance from the Peabody River, opposite the hotel, to the summit is nine miles, and in this distance we ascend 4,656 feet, the total height being 6,288 feet above the sea.[1] Formerly only a bridle path led up this ascent; but now access can be had to the summit by carriage roads and by rail.

These royal roads to the summit are, however, too democratic for the taste of some visitors, who mourn the olden days of ponies, guides and adventures; and though they give an excellent view of the geological structure of the mountain, they do not afford a good opportunity for the study of the alpine flora, which is one of the chief attractions of Mount Washington. For this reason, though I availed myself of the new road for gaining a general idea of the features of the group, I determined to ascend by Tuckerman's Ravine, a great chasm in the mountain side, named in honour of the indefatigable botanist of the

[1] According to Guyot, but some recent surveys make it a little higher.

North American lichens.[1] I was aided in this by the kindness of a gentleman of Boston, well acquainted with these hills, and passionately fond of their scenery.[2] Our party, in addition to this gentleman and myself, consisted of two ladies, two children, and two experienced guides, whose services were of the utmost importance, not only in indicating the path, but in removing windfalls and other obstructions, and in assisting members of the party over difficult and dangerous places.

We followed the carriage road for two miles, and then struck off to the left by a bridle path that seemed not to have been used for several years—the gentlemen and guides on foot, the ladies and children mounted on the sure-footed ponies used in these ascents. Our path wound around a spur of the mountain, over rocky and uneven ground, much of the rock being mica slate, with beautiful cruciform crystals of andalusite, which seemed larger and finer here than in any other part of the mountain which I visited. At first the vegetation was not materially different from that of the lower grounds, but as we gradually ascended we entered the " evergreen zone," and passed through dense thickets of small spruces and firs, the ground beneath which was carpeted with moss, and studded with an immense profusion of the delicate little mountain wood sorrel (*Oxalis acetosella*), a characteristic plant of wooded hills on both sides of the Atlantic, and which I had not before seen in such profusion since I had roamed on the hills of Lochaber Lake in Nova Scotia. Other herbaceous plants were rare, except ferns and club mosses; but we picked up an aster (*A. acuminatus*), a golden rod (*Solidago thyrsoidea*), and the very pretty tway blade (*Listera cordata*), a species[3] very widely distributed throughout British America.

[1] Peck, Bigelow and Booth were the early botanical explorers of the White Mountains; though Pursh was the first to determine some of the more interesting plants, and Oakes and Tuckerman deserve honourable mention, as the most thorough modern explorers.

[2] Mr. Raymond.

[3] *L. macrophylla Pursh* (Macoun).

In ascending the mountain directly, the spruces of this zone gradually degenerate, until they present the appearance of little gnarled bushes, flat on top and closely matted together, so that except where paths have been cut, it is almost impossible to penetrate among them. Finally, they lie flat on the ground, and become so small that, as Lyell remarks, the reindeer moss may be seen to overtop the spruces. This dwarfing of the spruces and firs is the effect of adverse circumstances, and of their struggle to extend their range toward the summit. Year by year they stretch forth their roots and branches, bending themselves to the ground, clinging to the bare rocks, and availing themselves of every chasm and fissure that may cover their advance; but the conditions of the case are against them. If their front advances in summer, it is driven back in winter, and if in a succession of mild seasons they are able to gain a little ground, less favourable seasons recur, and wither or destroy the holders of their advanced positions. For thousands of years the spruces and firs have striven in this hopeless escalade, but about 4,000 feet above the sea seems to be the limit of their advance, and unless the climate shall change, or these trees acquire a new plasticity of constitution, the genus *Abies* can never displace the hardier alpine inhabitants above, and plant its standard on the summit of Mount Washington.

I was struck by the similarity of this dwarfing of the upper edges of the spruce woods, to that which I have often observed on the exposed northern coasts of Cape Breton and Prince Edward Island, where the woods often gradually diminish in height toward the beach or the edge of a cliff, till the external row of plants clings closely to the soil, or rises above it only a few inches. The causes are the same, but the appearance is more marked on the mountain than on the coast. It is in miniature a picture of the gradual dwarfing of vegetation in the great barren grounds of Arctic America.

On the path which we followed, before we reached the upper

limit of trees, we arrived at the base of a stupendous cliff, forming the termination of a promontory or spur of the mountain, separating Tuckerman's Ravine from another deep depression known as the Great Gulf. From the top of this precipice poured a little cascade, that lost itself in spray long before it touched the tops of the trees below. The view at this place was the most impressive that it was my fortune to see in these hills.

Opposite the mouth of the Great Gulf, and I suppose at a height of about 3,000 feet, is a little pond known as Hermit Lake. It is nearly circular, and appears to be retained by a ridge of stones and gravel, perhaps an old moraine or sea beach. On its margin piped a solitary sandpiper, a few dragon flies flitted over its surface, and tadpoles in the bottom indicated that some species of frog dwells in its waters. High overhead, and skirting the edges of the precipices, soared an eagle, intent, no doubt, on the hares that frequent the thickets of the ravines.

Before we reached Hermit Lake we had been obliged to leave our horses, and now we turned aside to the left and entered Tuckerman's ravine, where there is no path, but merely the bed of a brook, whose cold clear water tumbles in a succession of cascades over huge polished masses of white gneiss, while on both sides of it the bottom of the ravine is occupied by dense and almost impenetrable thickets of the mountain alder (*Alnus viridis*).

Tuckerman's Ravine has been formed originally either by a subsidence of a portion of the mountain side, or by the action of the sea. It is, like most of the ravines and "gulfs" of these hills, a deep cut or depression bounded by precipitous sides and terminating at the top in a similarly precipitous manner. It must at one period have been in part filled with boulder clay, steep banks of which still remain in places on its sides; and extensive landslips have occurred, by which portions of the limit-

ing cliffs have been thrown toward the centre of the valley, in large piles of angular blocks of gneiss and mica slate, in the spaces between which grow gnarled birches and spruces that must be used as ladders and bridges whereby to scramble from block to block, by every one who would cross or ascend one of these rivers of stones. These "gulfs" of the White Mountains are similar to the "cirques" of the Alps, and various explanations have been given of their origin. To me they have always appeared to be of the same nature with the "chines" or bays with precipitous ends seen on rocky coasts, and which are produced by the action of the surf on the softer beds or veins of rock. They testify to the raging of the waves for long ages against the sides of what are now lofty mountains. This, we know, must have occurred in the great Pleistocene submergence; but in mountains so old as those now in question, it may have in part been effected in previous periods.

At the head of the ravine we paused to rest, to admire the wild prospect presented by the ravine and its precipitous sides, and to collect the numerous plants that flower on the surrounding slopes and precipices. Here, on the 19th of August, were several large patches of snow, one of them about a hundred yards in length. From the precipice at the head of the ravine poured hundreds of little rills, and several of them collecting into a brook, had excavated in the largest mass of snow a long tunnel or cavern with an arched and groined roof. Under the front of this we took our mid-day meal, with the hot August sun pouring its rays in front of us, and icy water gurgling among the stones at our feet. Around the margin of the snow the vegetation presented precisely the same appearances which are seen in the low country in March and April, when the snow banks have just disappeared—the old grass bleached and whitened, and many perennial plants sending up blanched shoots which had not yet experienced the influence of the sunlight.

The vegetation at the head of this ravine and on the precipices that overhang it, presents a remarkable mixture of lowland and mountain species.. The head of the ravine is not so high as the limit of trees already stated, but its steep sides rise abruptly to a plateau of 5,000 feet in height, intervening between Mount Washington and Mount Munro, and on which are the dark ponds or tarns known as the Lakes of the Clouds, forming the sources of the Amonoosook river, which flows in the opposite direction. From this plateau many alpine plants stretch downward into the ravine, while lowland plants, availing themselves of the shelter and moisture of this *cul-de-sac*, climb boldly upward almost to the higher plateau. Other species again occur here, which are found neither on the exposed alpine summits and ridges, nor in the low country. Conspicuous among the hardy climbers are two coarse and poisonous weeds of the river valleys, that look like intruders into the company of the more dwarfish alpine plants ;—the cow parsnip (*Heracleum lanatum*) and the white hellebore (*Veratrum viride*). Both of these plants were seen struggling up through the ground at the margin of the snow, and climbing up moist hollows almost to the tops of the precipices. Some specimens of the latter were crowded with the infant caterpillars of a mountain butterfly or moth. Less conspicuous, and better suited to the surrounding vegetation, were the bluets (*Oldenlandia cœrulea*), now in blossom here, as they had been months before in the low country, the dwarf cornel (*Cornus Canadensis*), and the twin flower (*Linnæa borealis*), the latter reaching quite to the plateau of the Lake of the Clouds, and entering into undisputed companionship with the truly alpine plants, though it is also found at Gorham, 4,000 feet lower.

Of the plants which seemed to be confined, or nearly so, to the upper part of the ravine, one of the most interesting was the northern painted cup (*Castelleia septentrionalis*), a plant which abounds on the coast of Labrador, and extends thence

through all Arctic North America to the Rocky Mountains, and is perhaps identical with the *C. Sibirica* of Northern Asia and the *C. pallida* of Northern Europe. Large beds of it were covered with their pale yellow blossoms on the precipitous banks overhanging the head of the ravine. With the painted cup, and here alone, was another beautiful species of a very different order, the northern green orchis (*Platanthera hyperborea*), a plant which occurs, though rarely, in Canada, but is more abundant to the northward. Here also occurred Peck's geum (*G. radiatum*, *var.*), *Arnica mollis*, and several other interesting plants.

Of the alpine plants which descend into the ravine, the most interesting was the Greenland sandwort (*Arenaria* (*Alsine*) *Grœnlandica*) which was blooming abundantly, with its clusters of delicate white flowers, on the very summit of the mountain, and could be found here and there by the side of the brook in the bottom of the ravine.

Clambering by a steep and dangerous path up the right side of the ravine, we reach almost at once the limit, beyond which the ordinary flora of New England can extend no longer, and are in the presence of a new group of plants comparable with those of Labrador and Greenland. Here, on the plateau of the Lake of the Clouds, the traveller who has ascended the giddy precipices overhanging Tuckerman's Ravine is glad to pause, that he may contemplate the features of the new region which he has reached. We have left the snow behind us, except a small patch which lingers on the shady side of Mount Munro; for it is only in the ravines into which it has drifted a hundred feet deep or more, that it can withstand the summer heat until August. We stand on a dreary waste of hard angular blocks of mica slate and gneiss that lie in rude ridges, as if they had been roughly raked up by Titans, who might have been trying to pile Monro upon Washington, but which seem to be merely the remains of the original outcropping edges of the rocks broken up

by the frost, but not disturbed or rounded by water.[1] Behind us is the deep trench-like ravine out of which we have climbed; on the left hand a long row of secondary summits stretching out from Mount Washington to the south-westward, and designated by the names of a series of American statesmen. In front this range descends abruptly in great wooded spurs or buttresses to the valley of the Amonoosook, which shines in silvery spots through the trees far below. On our right hand towers the peak of Mount Washington, still more than a thousand feet above us, and covered with angular blocks, as if it were a pile of fragments rather than a solid rock. These stones all around and up to the summit of the mountain, are tinted pale green by the map lichen (*Lecidea geographica*), which tinges in the same way the alpine summits of European mountains. Between the blocks and on their sheltered sides nestle the alpine flowering plants, of which twenty species or more may be collected on this shoulder of the mountain, and some of which extend themselves to the very summit, where *Alsine Grœnlandica* and the little tufts of deep green leaves of *Diapensia Lapponica* with a few Carices seem to luxuriate. Animal life accompanies these plants to the summit, near which I saw a family of the snow bird, evidently summer residents here, instead of seeking the far north for a breeding place, as is the habit of the species, and a number of insects, conspicuous among which was a brown butterfly of the genus *Hipparchia*. Shortly before sundown, when the thermometer at the summit house was fast settling toward the freezing point, a number of swallows were hawking for flies at a great height above the highest peak. To what

[1] Hitchcock has since found travelled blocks on the summit, bearing evidence to its submergence under the waves of the glacial sea, and to the grinding of ice floes upon it. Such a fact helps to account for the broken character of the summit, and also implies that unequal subsidence of the land elsewhere referred to, since we know of no agency which could carry boulders so high as the present mountain top.

species they belonged I could not ascertain. Possibly the cliff swallows find breeding places in the sides of the ravines, and rise over the hill top to bask in the sunbeams, after the mountain has thrown its shadows over their homes.

To return to the Alpine flora which is peculiar to the peaks of these mountains—are the species comprising it autochthones originating on these hill tops, and confined to them, or are they plants occurring elsewhere, and if so, where? and how and when did they migrate to their present abodes? These are questions which must occur to every one interested in geology, botany, or physical geography.

Not one of the Alpine plants of Mount Washington is peculiar to the place. Nearly all of them are distinct from the plants of the neighbouring lowlands, but they occur on other hills of New England and New York, and on the distant coasts of Labrador and Greenland, and some of them are distributed over the Arctic regions of Europe, Asia and America. In short, they are stragglers from that Arctic flora which encompasses the north polar region, and extends in promontories and islands along the high cold mountain summits far to the southward.

Some of the humble flowerless plants of these hills are of nearly world-wide distribution. I have already noticed the pale green map lichen which tints the rocks of the Pyrenees, the Alps, and the Scottish Highlands; and the curious ring lichen (*Parmelia centrifuga*) paints its conspicuous rings and arcs of circles alike on Mount Washington and the Scottish hills. A little club moss (*Lycopodium selago*) is not only widely distributed over the northern hemisphere, but Hooker has recognised it in the Antarctic regions. Not long ago we unrolled in Montreal an Egyptian mummy, preserved in the oldest style of embalming, and found that, to preserve the odour of the spices, quantities of a lichen (*Evernia furfuracea*) had been wrapped around the body, and have no doubt been imported into Egypt from Lebanon, or the hills of Macedonia, for such uses. Yet

the specimens from this old mummy were at once recognised by Professor Tuckerman as identical with this species as it occurs on the White Hills and on Katahdin, in Maine. These facts are, however, easily explicable in comparison with those that relate to the flowering plants.

The spores of lichens and mosses float lighter than the lightest down in the air, and may be wafted over land and sea, and dropped everywhere to grow where conditions may be favourable. We can form an idea of this from the fact that the volcanic dust, consisting of shreds of pumice, etc., thrown up by the eruption of Krakatoa, in 1883, was wafted, in a day or two, round the globe, and remained suspended for months in the atmosphere. The spores of many cryptogamous plants are even lighter than volcanic dust. Had the Egyptian embalmer used some of the first created specimens of *Evernia furfuracea*, it might easily, within the three thousand years or so since his work was done, have floated round the world and established itself on the White Hills. But, as we shall see, neither the time nor means would suffice for the flowering plants. The only available present agency for the transmission of these would be in the crops or the plumage of the migratory birds ; and when we consider how few of these, on their migrations from the north, could ever alight on these hills, and the rarity of their carrying seeds in a state fit to vegetate, and further, that few of these plants produce fruits edible by birds, or seeds likely to attach themselves to their feathers, the chances become infinitely small of their transmission in this way. The most profitable course of investigation in this and most other cases of apparently unaccountable geographical distribution, is to inquire as to the past geological conditions of the region, and how these may have affected the migrations of plants.

The earlier geological history of these mountains far antedates our existing vegetation. It belongs, in the first instance, to the Archæan and early Palæozoic period, in which the

materials of these mountains were accumulating, as beds of clay and gravel, in the sea bottom. These were buried under great depths of newer deposits, and were folded and crumpled by lateral pressure, baked and metamorphosed into their present crystalline condition.[1] Again heaved above the sea level, they were hewn by the action of the waves to some degree into their present forms, and constituted part of the nucleus of the American continent in the later Tertiary period, when they were probably higher than now. They were again, with all the surrounding land, depressed under the sea in the Pleistocene period, and in the Post-glacial or modern, slowly upheaved again to their present height. These last changes are those that concern their present flora, and their relations to it are well stated by Sir C. Lyell in the following passages from his interesting account of his ascent of Mount Washington in 1840.

"If we attempt to speculate on the manner in which the peculiar species of plants now established on the highest summits of the White Mountains were enabled to reach those isolated spots, while none of them are met with in the lower lands around, or for a great distance to the north, we shall find ourselves trying to solve a philosophical problem which requires the aid, not of botany alone, but of geology, or a knowledge of the geographical changes which immediately preceded the present state of the earth's surface. We have to explain how an Arctic flora, consisting of plants specifically identical with those which inhabit lands bordering the sea in the extreme north of America, Europe and Asia, could get to the top of Mount Washington. Now geology teaches us that the species living at present on the earth are older than many parts of our existing continents; that is to say, they were created before a large portion of the existing mountains, valleys, plains, lakes,

[1] While the mass of the White Mountains is probably older than the Silurian, there are beds of mica schist which contain corals of the genus Halysites, and stems of large crinoids.

rivers, and seas were formed. That such must be the case in regard to Sicily I announced my conviction in 1833, after first returning from that country; and a similar conclusion is no less obvious to any naturalist who has studied the structure of North America, and observed the wide area occupied by the modern or glacial deposits, in which marine shells of living but northern species are entombed. It is clear that a great portion of Canada, and the country surrounding the great lakes, was submerged beneath the ocean when recent species of molluska flourished, of which the fossil remains occur about 500 feet above the level of the sea at Montreal. Lake Champlain was a gulf or strait of the sea at that period, large areas in Maine were under water, and the White Mountains must then have constituted an island or group of islands. Yet, as this period is so modern in the earth's history as to belong to the epoch of the existing marine fauna, it is fair to infer that the Arctic flora, now contemporary with this, was then also established on the globe.

"A careful study of the present distribution of animals and plants over the globe has led nearly all the best naturalists to the opinion that each species had its origin in a single birthplace, and spread gradually from its original centre to all accessible spots fit for its habitation, by means of the powers of migration given to it from the first. If we adopt this view, or the doctrine of specific centres, there is no difficulty in comprehending how the *Cryptogamous* plants of Siberia, Lapland, Greenland and Labrador scaled the heights of Mount Washington, because the sporules of the fungi, lichens and mosses may be wafted through the air for indefinite distances, like smoke; and, in fact, heavier particles are actually known to have been carried for thousands of miles by the wind. But the cause of the occurrence of Arctic plants of the *Phænogamous* class on the top of the New Hampshire Mountains, specifically identical with those of remote polar regions, is by no means so obvious. They could not in the present condition of the earth effect a

passage over the intervening lowlands, because the extreme heat of summer and cold of winter would be fatal to them. We must suppose, therefore, that originally they extended their range in the same way as the plants now inhabiting Arctic and Antarctic lands disseminate themselves. The innumerable islands in the polar seas are tenanted by the same species of plants, some of which are conveyed as seeds by animals over the ice, when the sea is frozen in winter, or by birds; while a still larger number are transported by floating icebergs and field ice, on which soil containing the seeds of plants may be carried in a single year for hundreds of miles. A great body of geological evidence has now been brought together to show that this machinery for scattering plants, as well as for carrying erratic blocks southward, and polishing and grooving the floor of the ancient ocean, extended in the western hemisphere to lower latitudes than that of the White Mountains. When these last still constituted islands, in a sea chilled by the melting of floating ice, we may assume that they were covered entirely by a flora like that now confined to the uppermost or treeless region of the mountains, except in such portions of the period as were sufficiently cold to clothe their summits permanently in snow. As the continent grew by the slow upheaval of the land, and the islands gained in height, and the climate around these hills grew milder, the Arctic plants would retreat to higher zones, and finally occupy an elevated area, which probably had been, at first, or in the Glacial period, always covered with perpetual snow. Meanwhile the newly formed plains around the base of the mountain, to which northern species of plants could not spread, would be occupied by others migrating from the south, and perhaps by many trees, shrubs, and plants, then first created, and remaining to this day peculiar to North America."

The time to which the above views of Sir. C. Lyell would refer the migration of the White Mountain flora, is historically, very remote. The changes of level which have submerged the

American continent and re-elevated its land have occupied long periods. Whether, with Lyell, we measure these periods by the recession of the Falls of Niagara, or by the growth of the alluvial plain of the Mississippi; or, with Agassiz, by the extension of the peninsula of Florida, or endeavour to estimate the time required for the abrasion and deposition of the great mass of clay that fills the valley of the St. Lawrence, and allowing for the reductions of the antiquity of the Glacial period arising from recent observations and calculations, we cannot suppose that less than 8,000 or 10,000 years have elapsed since the Alpine plants of the White Mountains were cut off from all connection with their Arctic relatives. Their reign upon the mountain tops not only antedates all human dynasties, but probably reaches beyond the creation of man himself, and many of his contemporaries.

Positive evidence of the existence of some of these plants during a large portion of this lapse of time has actually been preserved in the Pleistocene deposits of Canada. At Green's Creek, on the Ottawa, in nodules in the clay containing marine shells, and coëval with the Leda clay of Montreal, there are numerous remains of plants that have been embedded in this clay at a time when the Ottawa valley was a bay or estuary, and when the Adirondack Mountains of New York and the mountains of New England were two rocky islands, separated from each other and from the mainland on the north by wide arms of the sea. The plants found in these nodules all appear to be of modern species. Several of these plants are found on the White Mountains, and they are all northern or boreal, but scarcely Arctic, belonging as they do to the southern margin of the Arctic land species. I have no doubt that further examination of these deposits will lead to the discovery of additional examples. This fact, proving as it does the existence of these species at the period in which the theory of Lyell and Forbes requires them to have migrated, is in itself strong corroborative

evidence. We can say that some of these species were waiting on the shores of the north, ready to be drifted to the insular spots to the south-west, and that their seeds were actually being washed out to sea by the streams which emptied themselves into the then estuary of the Ottawa.

Another aspect of the inquiry is that which relates to the reduction of temperature, which might be consequent on the great depression of the land which we know to have existed at the close of the Tertiary period, a fact on which I have insisted in former papers on the Pleistocene deposits of Canada.[1] A very clever writer on the subject of geographical distribution[2] has pictured the case of a subsiding continent, with the fauna and flora of its lowlands becoming gradually concentrated on the spots which had previously been Alpine summits, but now reduced to low and temperate islands. But he has left out of view the fact, that if land still existed in mass in the Arctic regions, and if the subsidence was that of land in temperate regions, and if the remaining islands were encompassed with cold and ice-laden currents, then, on the principles long ago so well stated by Sir C. Lyell, these islands might have a mean temperature far below that of the former plains, and might, in consequence, be suitable only to such an Alpine flora as that which they had previously borne.

Now this is precisely what seems to have occurred in the Pleistocene period. The Arctic land remained in great mass, detaching into the sea annual crops of icebergs and fields of coast ice, which have strewed all the northern hemisphere with boulders: the temperate regions were submerged, except a few insular spots. These are the very conditions required for a low mean temperature, both in the sea and on the land, and these geographical conditions correspond precisely with the facts as indicated by the fossil animals and plants of the

[1] *Canadian Naturalist*, vol. iv. [2] Wollaston.

period. We must bear in mind, however, that under certain contingencies the high mountain summits might have been clad in snow and ice, like Greenland, and the Alpine plants might have been able to live only on their margins.

Further, it would be easy to show that the Alpine plants of Mount Washington would thrive under such conditions as those supposed, at the sea level; a low and equable temperature, with a moist atmosphere, being that which they most desire, and their greatest enemy being the dry parching heat of the plains of the temperate regions. Those of them, such as *Potentilla tridentata* and *Alsine Grœnlandica*, which occur in low ground within the limits of the United States, are found under shaded woods, in damp ravines, or on the moist sea-coast; and as we follow the coasts northward, we find these plants, on these and on neighbouring islands, in lower latitudes than those in which they occur inland. This is well seen in Northern New Brunswick and in the south shore of the St. Lawrence, where several northern species occur in shady and moist localities. I have, for example, collected *Cornus Suecica* and the Alpine birch in such places. When the summer mists roll around the summit of Mount Washington, it is in every respect the precise counterpart of an islet anywhere on the coast of America, from Cape Breton to the Arctic seas, and when winter wraps everything in a mantle of snow, all these lands are in like manner under the same conditions. So, in the Pleistocene period, though the islets of the White Mountains may have experienced a less degree of winter cold, they must have had very nearly the same summer temperature as now; and as this is the season of growth for our Alpine and Arctic plants, it is its character that determines the suitableness of the locality to them.

Those stupendous vicissitudes of land and water which have changed the aspect of continents, and swept into destruction races of gigantic quadrupeds, have dealt gently with these

Alpine plants, which long ages ago looked out upon a waste of ice-laden waters that had engulfed the Pliocene land with all its inhabitants, as securely as they now look down upon the pleasant valleys of New England. It is curious, too, that the humbler tenants of the sea have shared a similar exemption. In the clay banks of the Saco, on the shores of Lake Champlain, and mixed with the remains of these very plants in the valley of the Ottawa, are shells that now live in the Gulf of St. Lawrence and on the coast of Maine, intermixed with other species that are now found only in a few bays of the Arctic seas. Just as in the Post-pliocene clays of the Ottawa, the remains of northern plants are found in the same nodule with those of *Leda glacialis*, so now similar associations may be taking place on the coasts at the mouth of the Great Fish River. Truly, in nature as in grace, God hath chosen the weak things of the world to confound those that are mighty, and has left in the earth's geological history, monuments of His respect and regard for the humblest of His works.

It is interesting to notice here that Greenland, at the present time, presents conditions as to vegetation which may, in some respects, correspond to those of the White Mountains in Pleistocene times. Its flora, though altogether Arctic, contains 386 species, none of which are peculiar to it, but many of them range quite round the Polar circle. Of those that are not so generally distributed, some, more especially on the west coast, are common to Greenland and Arctic America. Others, and a larger number, more especially on the east coast, are common to Greenland, Iceland and Norway, between which and Greenland there may have been a closer land connection than now, in Pliocene and Post-glacial times.

We look in vain among the Alpine plants, so long isolated in these mountains, for any evidence of decided change in specific characters. The Alpine plants, for ages separated from their Arctic brethren, are true to their kinds, and show little ten-

dency to vary, and none to adapt themselves to new forms in the sunny plains below. This is especially noteworthy on Mount Washington and the neighbouring peaks, because the soil of these is the same with that of the valleys. Several of the plants peculiar to these hills, as the black crowberry (*Empetrum nigrum*), for instance, even when other conditions are favourable, shun rich calcareous soils, and affect those of granitic origin. In many cases the difference in soil is a sufficient reason for the non-occurrence of such plants, except on certain hills. At Murray Bay, and on the shores of Lake Superior, the plant above named occurs only on the Laurentian gneiss. In Nova Scotia, its relative, *Corema Conradi*, is confined to the granite barrens of the south coast. Many such plants skirt the whole Laurentian range from Labrador to Lake Superior, but refuse to extend themselves over the calcareous plains of Canada. But in the White Hills the soil of the river alluvium is the same micaceous sand that fills the crevices of the rocks in the mountains, and hence there is no obstruction, in so far as soil is concerned, to the diffusion of plants upward and downward in the hills. In like manner there is every possible condition as to moisture and dryness, sunshine and shade, in both localities. These circumstances are of all others the most favourable to such variation as these plants are capable of undergoing. The case is the same with that which Hugh Miller so strongly puts in relation to the species of algæ that occur at different distances below high water mark on the coast of Scotland, each species there attaining a certain limit, and then, instead of changing to suit the new conditions, giving place to another. So it is on Mount Washington; and this, whether we regard the lowland plants that climb to a certain height, and there stop, the plants that are common to the base and summit, or the plants that are confined to the latter.

I have already referred to the evident struggle of the spruces and firs, and the plants associated with them, to ascend the

mountain, and the same remark applies to all the plants that one after another cease to appear at various heights from the lower valleys. One by one they become stunted and depauperated, and then cease, without any semblance of an attempt to vary into new and hardier forms. And this must have been proceeding, be it observed, from all those thousands of years that have elapsed since the elevation of the mountains out of the glacial seas. It is to be observed, also, that the new plants that occur in ascending, often belong to different genera and families from those left behind, not to closely allied species; and in the few cases in which this last kind of change occurs, there is no graduation into intermediate forms. For instance, *Solidago thyrsoidea* and *S. virga-aurea*[1] occur around the base of the mountain, and for some distance up its sides. At the height of four to five thousand feet the latter only remains, and this in a dwarfish condition. This corresponds to its distribution elsewhere, for, according to Richardson, it occurs in lat. 55° to 65° in Arctic America, and according to Hooker, it is found in the Rocky Mountains, while it also occurs in the hills of Scotland, and very abundantly in some parts of Norway. In the White Mountains *S. thrysoidea* prevails toward the base, *S. virga-aurea* toward the summit; and at the top of Tuckerman's ravine I found the former of these golden rods in blossom, within a few hundred feet of the latter, each preserving its distinctive peculiarities. Much has lately been said of the appearance of specific diversity that results from the breaking up of the continuity of the geographical areas of plants by geological changes; but here we probably have the converse of this. The mountain species is no doubt a part of the older Arctic flora, the other perhaps belong to a more modern flora, and they have met on the sides of the White Hills.

[1] Macoun thinks that most of the specimens referred to this species belong to the allied form, *S. Mulltinallata*, Ast, which is very extensively distributed on the mountains of British America and in the Arctic regions.

Some hardy species climb from the plains to heights of 5,000 feet or more, with scarcely even the usual change of being depauperated, and then suddenly disappear. This is very noteworthy in the case of two woodland plants, the dwarf cornel or pigeon berry (*Cornus Canadensis*), and the twin-flower (*Linnæa borealis*). The former of these is a plant most widely distributed over northern America, and probably belongs to that newer flora which overspread the continent after its re-elevation. In August this plant in the woods around the base of Mount Washington is loaded with its red berries. At an elevation of four to five thousand feet it may be found in bloom; above this a few plants appear, destitute of flowers, dwarfish in aspect, and nipped by cold, and then the species disappears. No doubt the birds that feed on its little drupes have carried it up the mountain, and have sown it a little farther up than the limit of its probable reproductiveness. The beautiful little *Linnæa* is a still more widely distributed plant; for it occurs on the hills of northern Europe, and is found across the whole breadth of the American continent from Nova Scotia to the Columbia River. It is almost beyond question a member of the old Arctic flora which colonized the islands of the Pleistocene sea, and has descended from them on all sides as the land became elevated. This plant also climbs Mount Washington to a height of 5,000 feet, and presents precisely the same characters on the top as at the bottom, only losing a little in the length of its stem. Specimens bearing blossoms, and quite in the same stage of growth, may be collected at the same time on the highest shoulders of Mount Washington, and on the flats at Gorham. The *Linnæa* in this is true to its designation. For, as if it belonged to it to support the reputation of the great systematist after whom it is named, it preserves its specific characters with scarcely a tittle of change throughout all its great range. One cannot see this hardy little survivor of the Glacial period, so unchanging yet so

gentle, so modest yet so adventurous, so wide in its migrations yet so choice in the selection of the mossy nooks which it adorns with its pendant bells, and renders fragrant with its delicious perfume, without praying that we might, in these days of petty distinctions and narrow views, be favoured with more such minds as that of the great Swede, to combine the little details of the knowledge of natural history into grand views of the unity of nature.

Another plant which, being less dependent on shade and shelter than the *Linnæa*, mounts still higher, is the cowberry or foxberry (*Vaccinium vitis-Idæa*). This, also, is both European and American, and is probably a survivor of the Pleistocene period. It still occurs in at least one locality in the low country of Massachusetts, and on the coast of Maine. It is found along the granitic coast of Nova Scotia, and extends thence northward to the Arctic circle, being found at Great Bear Lake and at Unalaska. This, too, is a most unchanging species, and the same statement may be made respecting the cloudberry (*Rubus Chamæmorus*), the black crowberry (*Empetrum nigrum*), the Labrador tea (*Ledum latifolium*), the three-toothed cinquefoil (*Potentilla tridentata*), which grows on the coast of Nova Scotia, and is found in the nodules of the Ottawa clay, the same in every detail as on Mount Washington, the bog bilberry (*Vaccinium uliginosum*), and the dwarf bilberry (*V. cæspitosum*). Several of these, too, it will be observed, are berry-bearing plants, whose seeds must be deposited in all kinds of localities by birds. Yet they never occur in the warm plains, nor do they show much tendency to vary in the distant and somewhat dissimilar places in which they occur. In the case of most of these species, the most careful comparison of specimens from Mount Washington with those from Labrador, shows no tittle of difference. When we consider the vast length of time during which such species have existed, and the multiplied vicissitudes through which

they have passed, one is tempted to believe that it is the tendency of the "struggle for existence" to confirm and render permanent the characters of species rather than to modify them.

Of the more specially Arctic plants which have held their ground unchanged on Mount Washington, the following are some of the principal. *Diapensia Lapponica*, in beautiful deep green tufts, ascends quite to the summit. It occurs also in the Adirondack Mountains, on Mount Katahdin, in Maine, and on the summit of Mount Albert, Gaspé (Macoun). It is found in Labrador, and, according to Hooker, extends north to Whale Island, in the Arctic seas; but it is not found west of the Great Fish River. It occurs also on the mountains of Lapland, and is described as the hardiest plant of that bleak region. *Arenaria* (*Alsine*) *Grœnlandica*, the Greenland sandwort, adorns with its clusters of white flowers every sandy crevice in the rocks of the very summit of Mount Washington, and is trodden under foot like grass by the hundreds of careless sightseers that haunt that peak in summer; though I should add, that not a few of them carry off little tufts as a memento of the mountains, along with the fragments of mica which appear to form the ordinary keepsakes of unscientific visitors. It is a most frail and delicate plant, seemingly altogether unsuited to the dangerous pre-eminence which it seeks, yet it loves the bare, unsheltered mountain peaks, and when it occurs in the more sheltered ravines, has only its stems a little longer and more slender. It occurs on the Adirondack Mountains and on Katahdin, where, if I may judge from specimens kindly sent to me by Prof. Goodale, it attains to smaller dimensions than on Mount Washington, on the Catskills, and at one place on the sea coast of Maine. I have not seen it in Nova Scotia, but it ranges north to Greenland.

Another of the truly Arctic plants is the alpine azalea (*Loiseleuria procumbens*), a densely tufted mountain shrub, with

hard glossy leaves, that look as if constructed to brave extremest hardships. It is found on the mountains of Norway, at the height of 3,550 feet on the Scottish hills, according to Watson, and according to Fuchs, at the height of 7,000 feet in the milder climate of the Venetian Alps. In America it is found in Newfoundland, in Labrador, at 4,000 feet on Mount Albert, Gaspé,[1] and in the barren grounds from lat. 65° to the extreme Arctic islands. Gray does not mention its occurrence elsewhere in the United States than the summits of the White Mountains. A member of the same family of the heaths, the yew-leaved phyllodoce (*P. taxifolia*), presents a still more singular distribution. It is found on all the higher mountains of New England and New York, and occurs also on the mountains of Scotland and Scandinavia, but its only known station in northern America is, according to Hooker, in Labrador. As many as nine or ten of the Alpine plants of the White Mountains belong to the order of the Heaths (*Ericaceæ*). Another example from this order is *Rhododendron Lapponicum*, a northern European species, as its name indicates, and scattered over all the high mountains of New England and New York, occurring also in Labrador, on the Arctic sea coasts, and the northern part of the Rocky Mountains, and at 4,000 feet on Mount Albert, Gaspé (Macoun).

It would be tedious to refer in detail to more of these plants, but I must notice two herbaceous species belonging to different families, but resembling each other in size and habit—the Alpine epilobium (*E. alpinum* or *alsinefolium*), and the Alpine speedwell (*Veronica alpina*). Both are in the United States confined to the highest mountain tops. Both occur as alpine northern plants in Europe, being found on the Alps, on the Scottish Highlands, and in Scandinavia. Both are found in Labrador and on the Rocky Mountains, and the *Veronica* ex-

[1] Macoun.

tends as far as Greenland. The Alpine epilobium is one of the few White Mountain plants that have attained the bad eminence of being regarded as doubtful species. Gray notes as the typical form, that with obtuse and nearly entire leaves, and as a variety, that with acute and slightly toothed leaves, which some other botanists seem to regard as distinct specifically. Thus we find that this little plant has been induced to assume a suspicious degree of variability; yet it is strange that both species or varieties are found growing together, as if the little peculiarities in the form of the leaves were matters of indifference, and not induced by any dire necessities in the struggle for life. Facts of this kind are curious, and not easily explained under the supposition either of specific unity or diversity. For why should this plant vary without necessity? and why should two species so much alike be created for the same locality? Perhaps these two species or varieties, wandering from far distant points of origin, have met here fortuitously, while the lines of migration have been cut off by geological changes; and yet the points of difference are too constant to be removed, even after the reason for them has disappeared. If this could be proved, it would afford a strong reason for believing the existence of a real specific diversity in these plants.

I have said nothing of the grasses and sedges of these mountains; but one of them deserves a special notice. It is the Alpine herd's grass (*Phleum alpinum*), a humble relation of our common herd's grass. This plant not only occurs on the White Mountains, in Arctic America, in the Canadian Mountains, from the summit of Mount Albert, in Gaspé, to the mountains of British Columbia, and on the hills of Scotland and Scandinavia, but has been found on the Mexican Cordillera and at the Straits of Magellan. The seeds of this grass may perhaps be specially suited for transportation by water, as well as by land. It is observed in Nova Scotia that when the wide flats of mud deposited by the tides of the Bay of Fundy,

are dyked in from the sea, they soon become covered with grasses and carices, the seeds of which are supposed to be washed down by streams and mingled with the marine silt; and fragments of grasses abound in the Post-tertiary clays of the Ottawa.

It seems almost ridiculous thus to connect the persistence of the form of a little plant with the subsidence and elevation of whole continents, and the lapse of enormous periods of time. Yet the Power which preserves unchanged from generation to generation the humblest animal or plant, is the same with that which causes the permanence of the great laws of physical nature, and the continued revolutions of the earth and all its companion spheres. A little leaf, entombed ages on ages ago in the Pleistocene clays of Canada, preserves in all its minutest features the precise type of that of the same species as it now lives, after all the prodigious geological changes that have intervened. An Arctic and Alpine plant that has survived all these changes maintains, in its now isolated and far removed stations, all its specific characters unchanged. The flora of a mountain top is precisely what it must have been when it was an island in the glacial seas. These facts relate not to hard crystalline rocks that remain unaltered from age to age, but to little delicate organisms that have many thousands of times died and been renewed in the lapse of time. They show us that what we call a species represents a decision of the unchanging creative will, and that the group of qualities which constitutes our idea of the species goes on from generation to generation animating new organisms constructed out of different particles of matter. The individual dies, but the species lives, and will live until the Power that has decreed its creation shall have decreed its extinction; or until, in the slow process of physical change depending on another section of His laws, it shall have been excluded from the possibility of existence anywhere on the surface of the earth, unless we suppose with

modern evolutionists that there is a possibility of these plants so changing their characters that in the lapse of ages they might appear to us to be distinct specific types. The fact, however, that the Arctic species have migrated around the whole Arctic circle, and have advanced southward and retreated to the north, again and again, without changing their constitutions or forms, augurs for them at least a remarkable fixity as well as continuity.

While the huge ribs of mother earth that project into mountain summits, and the grand and majestic movement of the creative processes by which they have been formed, speak to us of the majesty of Him to whom the sea belongs, and whose hand formed the dry land, the continuance of these little plants preaches the same lessons of humble faith in the Divine promises and laws, which our Lord drew from the lilies of the field.

It is suggestive, in connection with the antiquity and migrations of these plants, to consider the differences in this respect of some closely allied species of the same genera. Of the blueberries that grow on the White Mountains, one species, *Vaccinium uliginosum*, is found in Behring's Straits and very widely in Arctic and boreal America,[1] also in northern Europe. *V. cæspitosum* has a wide northern range in America, but is not European. *V. Pennsylvanicum* and *V. Canadense*, from their geographical distribution, do not seem to belong to the Arctic flora at all, but to be of more southern origin. The two bearberries (*Arctostaphylos uva-ursi* and *alpina*) occur together on the White Hills, and on the Scottish and Scandinavian mountains; but the former is a plant of much wider and more southern distribution in America than the latter. Two of the dwarf willows of the White Mountains (*Salix repens* and *S. herbacea*) are European as well as

[1] Macoun, Catalogue of Canadian plants.

American, but *S. uva-ursi* seems to be confined to America. *Rubus triflorus*, the dwarf raspberry, and *R. chamœmorus*, the cloud berry, climb about equally high on Mount Washington; but the former is exclusively American, and ranges pretty far southward, while the latter extends no farther south than the northern coast of Maine, and is distributed all around the Arctic regions of the Old and New Worlds. It is to be observed, however, that the former can thrive on rich and calcareous soils, while the latter loves those that are barren and granitic; but it is nevertheless probable that *R. triflorus* belongs to a later and more local flora. Similar reasons would induce the belief that the American dwarf cornel or pigeonberry (*Cornus Canadensis*), whose distribution is solely American, and not properly Arctic, is of later origin than the *C. Suecica*,[1] which occurs in northern America locally, and is extensively distributed in northern Europe.

I can but glance at such points as these; but they raise great questions which are to be worked out, not merely by the patient collection of facts, but by a style of scientific thought very much above those which, on the one hand, escape such problems by the supposition of multiplied centres of creation, or on the other, render their solution worthless by confounding races due to external disturbing causes with species originally distinct. Difficulties of various kinds are easily evaded by either of these extreme views; but with the fact before him of specific diversity and its manifestly long continuance, on the one hand, and the remarkable migrations of some species on the other, the true naturalist must be content to work out the problems presented to him with the data afforded by the actual observation of nature, following carefully the threads of guid-

[1] I have found *C. Suecica* growing along with *C. Canadensis* in shaded and northern exposures on the south side of the St. Lawrence, near Caconna and Metis. Its seeds may have been brought over from Labrador by migratory birds.

ance thus indicated, not rudely breaking them by too hasty generalizations.

But it is time to leave the scientific teachings of our little Alpine friends, and to inquire if they can teach anything to the heart as well as to the head.

The mountains themselves, heaving their huge sides to the heavens, speak of forces in comparison with which all human power is nothing; and we can scarcely look upon them in their majesty without a psalm of praise rising up within us to Him who made the sea, and from whose hands the dry land took its form. As we ascend them, and as our vision ranges more and more widely over the tops of wooded hills, along the courses of streams, over cultivated valleys, and to the shores of the blue sea itself, our mental vision widens too. We think that the great roots of these hills run beneath a whole continent, that their tops look down on the wide St. Lawrence plain, on the beautiful valleys of New England, and on the rice fields of the sunny south. We are reminded of the brotherhood of man, which overleaps all artificial boundaries, and should cause us to pray that throughout their whole extent these hills may rise amidst a happy, a free, and a God-fearing people.

Our Alpine plants have still higher lessons to teach. They are fitting emblems of that little flock, scattered everywhere, yet one in heart, and in all lands having their true citizenship in heaven. They tell us that it is the humble who are nearest God, and they ask why we should doubt the guardian care of the Father who cares for them. They witness, too, of the lowly and hidden ones who may inhabit the barren and lowly spots of earth, yet are special subjects of God's love, as they should be of ours. We may thus read in the Alpine plants truths that beget deeper faith in God, and closer brotherhood with His people.

The history of these plants has also a strange significance.

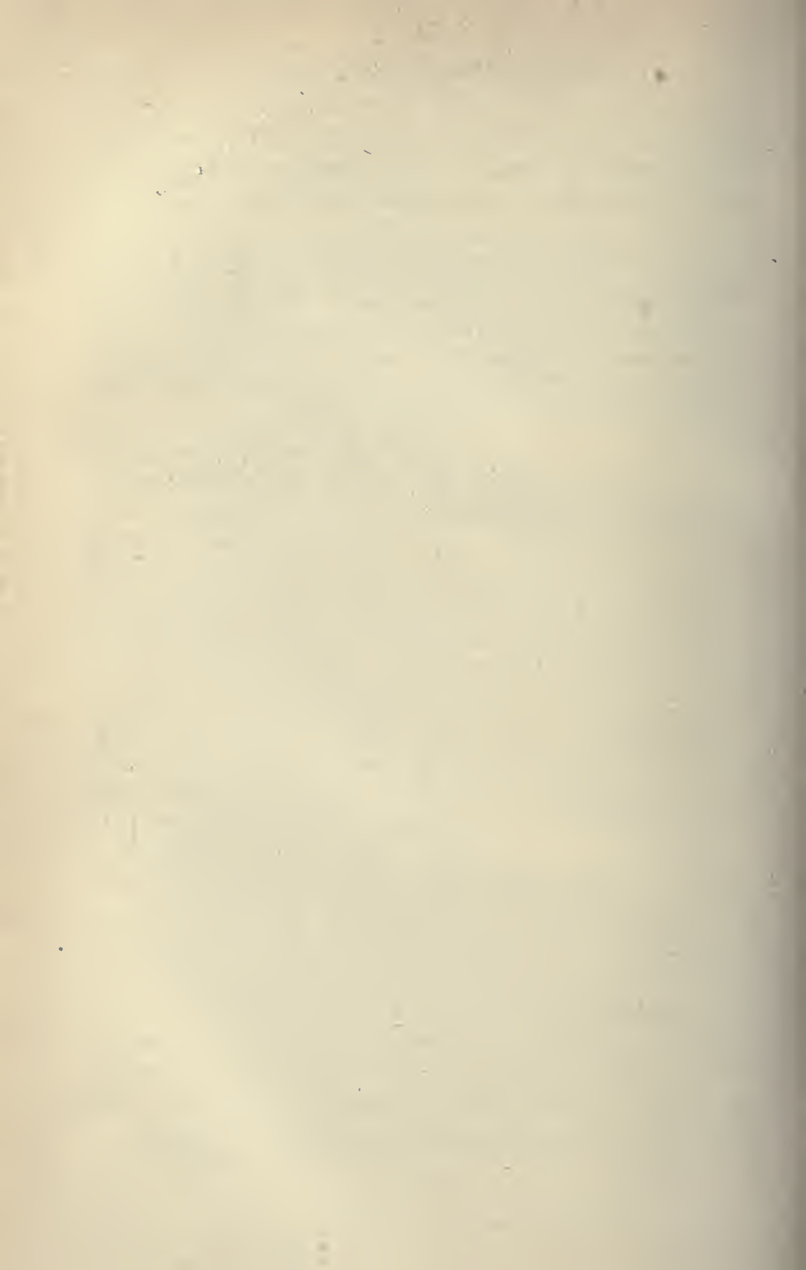
It might have been written of them, "Though the dry land be removed out of its place, and the mountains cast into the midst of the sea, yet the Lord will not forsake the work of His hands"; for this has been literally their history. In this they hold forth an omen of hope to the people of God in that once happy land through which these hills extend, and who now mourn the evil times on which they have fallen. The mountain plants may teach them that though the floods of strife should rise even to the tops of the hills, and leave but scattered islets to mark the place of a united land, their rock is sure, and their prayers will prevail.[1] The power that has waked the storm is after all their Father's hand. For years a cry has risen high above these hills: the cry of the bondman who has reaped the fields and received no hire. That cry is sure to be heard in heaven, whatever other prayers may go unanswered. An apostle tells us that it enters directly into the ears of the God of Sabaoth, and is potent to call down the day of slaughter on the proud ones of earth. The prayer of the slave has been answered; and the tempest is abroad, sweeping away his oppressors and their abettors. Yet God rules in all this, and those whom He has chosen will be spared, even like the hardy plants of the hill tops, to look again on a renewed and smiling land, from which many monsters and shapes of dread have for ever passed away.

But last of all, the Alpine flowers have a lesson that should come near to all of us individually. They tell us how well natural law is observed, as compared with moral. Obeying with unchanging fidelity the law of their creation, they have meekly borne the cold and storms of thousands of winters, yet have thankfully expanded their bosoms to the returning sun of every summer, and have not once forgot to open their tiny buds, and bring forth flowers and fruit, doing thus their little part to the

[1] This paper was originally written at the time when the American Civil War was raging.

glory of their Maker and ours. How would the moral wastes of earth rejoice and be glad, did the sunshine of God's daily favours evoke a similar response from every human heart!

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EARLY MAN.

DEDICATED TO THE MEMORY OF THE LATE

SIR DANIEL WILSON, LL.D., F.R.S.E.,

A DEAR AND VALUED FRIEND,

AND ONE OF THE MOST EMINENT AND JUDICIOUS STUDENTS OF PRE-HISTORIC MAN BOTH IN EUROPE AND AMERICA.

Summary of the Story of Early Man—Classification of Tertiary Time—Probabilities as to the Introduction of Man—The Anthropic Age as distinguished from the Pleistocene—Its Division into Palanthropic and Neanthropic—Sketches of Palanthropic Man and his Immediate Successors





Four Pre-historic Skulls. (p. 472.)

Outer outline, *Cromagnon ;* second, *Engis ;* third, *Cannstadt ;* fourth, *Canadian Hochelagan* on smaller scale.

CHAPTER XVII.

EARLY MAN.

THE science of the earth has its culmination and terminus in man; and at this, the most advanced of our salient points, as we look back on the long process of the development of the earth, we may well ask, Was the end worthy of the means? We may well have doubts as to an affirmative answer if we do not consider that the means were perfect, each in its own time, and that man, the final link in the chain of life, is that which alone takes hold of the unseen and eternal. He alone can comprehend the great plan, and appreciate its reason and design. Without his agency in this respect nature would have been a riddle without any solution—a column without a capital, a tree without fruit. Besides this, even science may be able to perceive that man may be not merely the legatee of all the ages that lie behind, but the heir of the eternity that lies before, the only earthly being that has implanted in him the germ and instinct of immortality.

Whatever view we may take of these questions, it is of interest to us to know, if possible, how and when this chief corner stone was placed upon the edifice of nature, and what are the precise relations of man to the later geological ages, as well as to the present order of nature, of which he is at once a part, and its ruler and head. Let us put this first in the form of a narrative based on geological facts only, and then consider some of its details and relations to history.

The Glacial age had passed away. The lower land, in great part a bare expance of mud, sand, and gravel, had risen from

the icy ocean in which it had been submerged, and most of the mountain tops had lost their covering of perennial snow and ice. The climate was ameliorated, and the sun again shone warmly on the desolate earth. Gradually the new land became overspread with a rich vegetation, and was occupied by many large animals. There were species of elephant, rhinoceros, hippopotamus, horse, bison, ox and deer, multiplying till the plains and river valleys were filled with their herds, in spite of the fact that they were followed by formidable carnivorous beasts fitted to prey on them. At this time, somewhere in the warm temperate zone, in an oasis or island of fertility, appeared a new thing on the earth, a man and woman walking erect in the forest glades, bathing in the waters, gathering and tasting every edible fruit, watching with curious and inquiring eyes the various animals around them, and giving them names which might eventually serve not merely to designate their kinds, but to express actions and emotions as well. When, where, and how did this new departure, fraught with so many possibilities, occur—introducing as it did the dexterous fingers and inventive mind of Man upon the scene? The last of these questions science is still unable to answer, and though we may frame many hypotheses, they all remain destitute of certain proof in so far as natural science is concerned. We can here only fall back on the old traditional and historical monuments of our race, and believe that man, the child of God, and with God-like intellect, will, and consciousness, was placed by his Maker in an Edenic region, and commissioned to multiply and replenish the earth. The when and where of his introduction, and his early history when introduced, are more open to scientific investigation.

That man was originally frugivorous, his whole structure testifies. That he originated in some favourable climate and fertile land is equally certain, and that his surroundings must have been of such a nature as to give him immunity from the

attacks of formidable beasts of prey, also goes without saying. These are all necessary conditions of the successful introduction of such a creature as man, and theories which suppose him to have originated in a cold climate, to struggle at once with the difficulties and dangers of such a position, are, from a scientific point of view, incredible.

But man was introduced into a wide and varied world, more wide and varied than that possessed by his modern descendants. The earliest men that we certainly know inhabited out continents in the second Continental age of the Kainozoic Period, when, as we know from ample geological evidence, the land of the northern hemisphere was much more extensive than at present, with a mild climate, and a rich flora and fauna. If he was ambitious to leave the oasis of his origin the way was open to him, but at the expense of becoming a toiler, an inventor, and a feeder on animal food, more especially when he should penetrate into the colder climates. The details of all this, as they actually occurred, are not within the range of scientific investigation, for these early men must have left few, if any, monuments; but we can imagine some of them. Man's hands were capable of other uses than the mere gathering of fruit. His mind was not an instinctive machine, like that of lower animals, but an imaginative and inventive intellect, capable of adapting objects to new uses peculiar to himself. A fallen branch would enable him to obtain the fruits that hung higher than his hands could reach, a pebble would enable him to break a nut too hard for his teeth. He could easily weave a few twigs into a rough basket to carry the fruit he had gathered to the cave or shelter, or spreading tree, or rough hut that served him for a home; and when he had found courage to snatch a brand from some tree, ignited by lightning, or by the friction of dry branches, and to kindle a fire for himself, he had fairly entered on that path of invention and discovery which has enabled him to achieve so many conquests over nature.

Our imagination may carry us yet a little farther with reference to his fortunes. If he needed any weapon to repel aggressive enemies, a stick or club would serve his purpose, or perhaps a stone thrown from his hand. Soon, however, he might learn from the pain caused by the sharp flints that lay in his path the cutting power of an edge, and, armed with a flint chip held in the hand, or fitted into a piece of wood, he would become an artificer of many things useful and pleasing. As he wandered into more severe climates, where vegetable food could not be obtained throughout the year, and as he observed the habits of beasts and birds of prey, he would learn to be a hunter and a fisherman, and to cook animal food ; and with this would come new habits, wants and materials, as well as a more active and energetic mode of life. He would also have to make new weapons and implements, axes, darts, harpoons, and scrapers for skins, and bodkins or needles to make skin garments. He would use chipped flint where this could be procured, and failing this, splintered and rubbed slate, and for some uses, bone and antler. Much ingenuity would be used in shaping these materials, and in the working of bone, antler and wood, ornament would begin to be studied. In the meantime the hunter, though his weapons improved, would become a ruder and more migratory man, and in anger, or in the desire to gain some coveted object, might begin to use his weapons against his brother man. In some more favoured localities, however, he might attain to a more settled life ; and he, or more likely the woman his helpmeet, might contrive to tame some species of animals, and to begin some culture of the soil.

It was probably in this early time that metals first attracted the attention of men. The ages of stone, bronze, and iron believed in by some archæologists, are more or less mythical to the geologist, who knows that these things depend more on locality and on natural products than on stages of culture. The analogy of America teaches us that the use of

different metals may be contemporaneous, provided that they can be obtained in a native state. At the time of the discovery of America the Esquimaux were using native iron, which, though rare in most parts of the world, is not uncommon in some rocks of Greenland. The people of the region of the great lakes, and of the valleys of the Mississippi and Ohio, were using native copper from Lake Superior for similar purposes. Gold was apparently the only metal among the natives of Central America. The people of Peru had invented bronze, or had brought the knowledge of it with them from beyond the sea. Thus the Peruvians were in the bronze age, the Mexicans and Mound builders in the copper age, and the Esquimaux in the iron age, while at the same time the greater part of the aboriginal tribes were at one and the same time in the ages of chipped and polished stone and in these ages what have been called palæolithic and neolothic weapons were contemporaneous, the former being most usually unfinished examples of the latter, or extemporized tools roughly made in emergencies.[1] How long this had lasted, or how long it would have continued, had not Europeans introduced from abroad an iron age, we do not know. It was probably the same in other parts of the world, in pre-historic times. In any case, the discovery of native metals must have occurred very early. Men searching in the beds of streams for suitable pebbles to form hammers and other implements, would find nuggets of gold and copper, and the properties of these, so different from those of other pebbles, would at once attract attention, and lead to useful applications. Native iron is of rarer occurrence, but in certain localities would also be found.[2] It must have been

[1] "Fossil Men," by the Author. W. H. Holmes, "American Anthropologist," 1890.

[2] The rarity of native iron, whether meteoric or telluric, and its rapid decay by rusting, sufficiently account for its absence in deposits where implements of stone and bone have been preserved.

experiments on these ores, which resemble the native metals in colour, lustre and weight, that led to the first attempts at smelting metals, and these must have occurred at a very early period. Yet for ages the metals must have been extremely scarce, and we know that in comparatively modern times civilized nations like the Egyptians were using flint flakes after they had domesticated many animals, had become skilful agriculturists and artisans, and had executed great architectural works.

Probably all these ends had been to some extent, and in some localities, attained in the earliest human period, when man was contemporary with many large animals now extinct. But a serious change was to occur in human prospects. There is the best geological evidence that in the northern hemisphere the mild climate of the earlier Post-glacial period relapsed into comparative coldness, though not so extreme as that of the preceding Glacial age. Hill tops, long denuded of the snow and ice of the Glacial period, were again covered, and cold winters sealed up the lakes and rivers, and covered the ground with wintry snows of long continuance, and with this came a change in animal life and in human habits. The old southern elephant (*E. antiquus*), the southern rhinoceros (*E. leptorhinus*), and the river hippopotamus (*H. major*), which had been contemporaries, in Europe at least, of primitive man, retired from the advancing cold, and ultimately perished, while their places were taken by the hairy mammoth (*E. primigenius*), the woolly rhinoceros (*R. tichorhinus*), the reindeer, and even the musk ox. Now began a fierce struggle for existence in the more northern districts inhabited by man—a struggle in which only the hardier and ruder races could survive, except, perhaps, in some of the more genial portions of the warm temperate zone. Men had to become almost wholly carnivorous, and had to contend with powerful and fierce animals. Tribe contended with tribe for the possession of the most productive and sheltered habitats. Thus the struggle

with nature became aggravated by that between man and man. Violence disturbed the progress of civilization, and favoured the increase and power of the rudest tribes, while the more delicately organized and finer types of humanity, if they continued to exist in some favoured spots, were in constant danger of being exterminated by their fiercer and stronger contemporaries.

In mercy to humanity, this state of things was terminated by a great physical revolution, the last great subsidence of the continents—that Post-glacial flood, which must have swept away the greater part of men, and many species of great beasts, and left only a few survivors to re-people the world, just as the mammoth and other gigantic animals had to give place to smaller and feebler creatures. In these vicissitudes it seemed determined, with reference to man, that the more gigantic and formidable races should perish, and that one of the finer types should survive to re-people the world.

The age of which we have been writing the history, is that which has been fitly named the Anthropic, in that earlier part of it preceding the great diluvial catastrophe, which has fixed itself in all the earlier traditions of men, and which separates what may be called the Palanthropic or Antediluvian age from the Neanthropic or Postdiluvian. Independently altogether of human history, these are two geological ages distinguished by different physical conditions and different species of animals; and the time has undoubtedly come when all the speculations of archæologists respecting early man must be regulated by these great geological facts, which are stamped upon those later deposits of the crust of the earth, which have been laid down since man was its inhabitant. If they have only recently assumed their proper place in the geological chronology, this is due to the great difficulty in the case of the more recent deposits in establishing their actual succession and relations to each other. These difficulties have, however, been overcome, and new facts are constantly being obtained to render our

knowledge more definite. Lest, however, the preceding sketch of the Palanthropic age—that in which gigantic men were contemporaries of a gigantic fauna now extinct—should be regarded as altogether fanciful, we may proceed to consider the geological facts and classification as actually ascertained.

The Tertiary or Kainozoic period, the last of the four great "times" into which the earth's geological history is usually divided, and that to which man and the mammalia belong, was ingeniously subdivided by Lyell, on the ground of percentages of marine shells and other invertebrates of the sea. According to this method, which with some modification in details is still accepted, the *Eocene*, or dawn of the recent, includes those formations in which the percentage of modern species of marine animals does not exceed $3\frac{1}{2}$, all the other species found being extinct. The *Miocene* (less recent) includes formations in which the percentage of living species does not exceed 35, and the *Pliocene* (more recent) contains formations having more than 35 per cent. of recent species. To these three may be added the *Pleistocene*, in which the great majority of the species are recent, and the *Modern* or Anthropic, in which we are still living. Dawkins and Gaudry give us a division substantially the same with Lyell's, except that they prefer to take the evidence of the higher animals instead of the marine shells. The Eocene thus includes those formations in which there are remains of mammals or ordinary land quadrupeds, but none of these belong to recent species or genera, though they may be included in the same families and orders with the recent mammals. This is a most important fact, as we shall see, and the only exception to it is that Gaudry and others hold that a few living genera, as those of the dog, civet, and marten, are actually found in the later Eocene. The Miocene, on the same mammalian evidence, will include formations in which there are living genera of mammals, but no species which survive to the present time.

The Pliocene and Pleistocene show living species, though in the former these are very few and exceptional, while in the latter they become the majority.

With regard to the geological antiquity of man, no geologist expects to find any human remains in beds older than the Tertiary, because in the older periods the conditions of the world do not seem to have been suitable to man, and because in these periods no animals nearly akin to man are known. On entering into the Eocene Tertiary we fail in like manner to find any human remains; and we do not expect to find any, because no living species and scarcely any living genera of mammals are known in the Eocene; nor do we find in it remains of any of the animals, as the anthropoid apes, for instance, most nearly allied to man. In the Miocene the case is somewhat different. Here we have living genera at least, and we have large species of apes; but no remains of man have been discovered, if we except some splinters of flint found in beds of this age at Thenay, in France, and some notched bones. Supposing these objects to have been chipped or notched by animals, which is by no means certain in the case of the flints, the question remains, Was this done by man? Gaudry and Dawkins prefer to suppose that the artificer was one of the anthropoid apes of the period. It is true that no apes are known to do such work now; but then other animals, as beavers and birds, are artificers, and some extinct animals were of higher powers than their modern representatives. But if there were Miocene apes which chipped flints and cut bones, this would, either on the hypothesis of evolution or that of creation by law, render the occurrence of man still less likely than if there were no such apes. The scratched and notched bones, on the other hand, indicate merely the gnawing of sharks or other carnivorous animals. For these reasons neither Dawkins nor Gaudry, nor indeed any geologists of authority in the Tertiary fauna, believe in Miocene man.

In the Pliocene, though the facies of the mammalian fauna of Europe becomes more modern, and a few modern species occur, the climate becomes colder, and in consequence the apes disappear, so that the chances of finding fossil men are lessened rather than increased in so far as the temperate regions are concerned. In Italy, however, Capellini has described a skull, an implement, and a notched bone supposed to have come from Pliocene beds. To this it may be objected that the skull—which I examined in 1883 in the museum at Florence—and the implement are of recent type, and probably mixed with the Pliocene stuff by some slip of the ground. As the writer has elsewhere pointed out,[1] similar and apparently fatal objections apply to the skull and implements alleged to have been found in Pliocene gravels in California. Dawkins further informs us that in the Italian Pliocene beds supposed to hold remains of man, of twenty-one mammalia whose bones occur, all are extinct species, except possibly one, a hippopotamus. This, of course, renders very unlikely in a geological point of view the occurrence of human remains in these beds.

In the Pleistocene deposits of Europe—and this applies also to America—we for the first time find a predominance of recent species of land animals. Here, therefore, we may look with some hope for remains of man and his works, and here, in the later Pleistocene, or the early Modern, they are actually found. When we speak, however, of Pleistocene man, there arise some questions as to the classification of the deposits, which it seems to the writer Dawkins and other British geologists have not answered in accordance with geological facts, and a misunderstanding as to which may lead to serious error. They have extended the term Pleistocene over that Post-glacial period in which we find remains of man, and thus have split the "Anthropic" period into two; and they proceed to divide the latter part of it into the Pre-historic and Historic periods,

[1] "Fossil Men," 1880.

whereas the name Pleistocene should not be extended to the Post-glacial age. The close of the Glacial period, introducing great physical and climatal changes, some new species of mammalia and man himself, should be regarded as the end of the Pleistocene, and the introduction of what some French geologists have called the *Anthropic* period, which I have elsewhere divided into Palanthropic, corresponding to the so-called Palæolithic age, and Neanthropic, corresponding to the later stone and metal ages.[1] These may be termed respectively the earlier and later stages of the Modern period as distinguished from the Pleistocene Tertiary.

In point of logical arrangement, and especially of geological classification, the division into historic and pre-historic periods is decidedly objectionable. Even in Europe the historic age of the south is altogether a different thing from that of the north, and to speak of the pre-historic period in Greece and in Britain or Norway as indicating the same portion of time is altogether illusory. Hence a large portion of the discussion of this subject has to be properly called "the overlap of history." Further, the mere accident of the presence or absence of historical documents cannot constitute a geological period comparable with such periods as the Pleistocene and Pliocene, and the assumption of such a criterion of time merely confuses our ideas. On the one hand, while the whole Tertiary or Kainozoic, up to the present day, is one great geological period, characterized by a continuous though gradually changing fauna and series of physical conditions, and there is consequently no good basis for setting apart, as some geologists do, a Quaternary as distinct from the Tertiary period; on the other hand, there is a distinct physical break between the Pliocene and the Modern in the great Glacial age. This, in its Arctic climate and enormous submergence of the land, though it did not exterminate the fauna of the northern hemisphere,

[1] "Modern Science in Bible Lands."

greatly reduced it, and at the close of this age some new forms came in. For this reason the division between the Pleistocene and Anthropic ages should be made at the beginning of the Post-glacial age. The natural division would thus be :—

I. PLEISTOCENE, including—

(*a*) *Early Pleistocene*, or first continental period. Land very extensive, moderate climate. This passes into the preceding Pliocene.

(*b*) *Later Pleistocene*, or glacial, including Dawkins' "Mid Pleistocene." In this there was a great prevalence of cold and glacial conditions, and a great submergence of the northern land.

II. ANTHROPIC, or period of man and modern mammals, including—

(*a*) *Palanthropic*, *Post-glacial*, or second continental period, in which the land was again very extensive, and Paleocosmic man was contemporary with some great mammals, as the mammoth, now extinct, and the area of land in the northern hemisphere was greater than at present. This includes a later cold period, not equal in intensity to that of the Glacial period proper, and was terminated by a great and very general subsidence, accompanied by the disappearance of Paleocosmic man and some large mammalia, and which may be identical with the historical deluge.

(*b*) *Neanthropic* or *Recent*, when the continents attained their present levels, existing races of men colonized Europe, and living species of mammals. This includes both the Prehistoric and Historic periods.

On geological grounds the above should clearly be our arrangement, though of course there need be no objection to such other subdivisions as historians and antiquarians may find desirable for their purposes. On this classification *the earliest certain indications of the presence of man in Europe, Asia, or America, so far as yet known, belong to the Modern or Anthropic*

period alone. That man may have existed previously no one need deny, but no one can at present positively affirm on any ground of actual fact. It may be necessary here to explain the contentions often made that in Britain and Western Europe man belongs to an interglacial period. When with Dr. James Geikie, the great Scottish glacialist, we hold that there were several interglacial periods, the Glacial age may be extended by including the warm period of the Palanthropic, and the cold at its termination, as one of the interglacial and Glacial periods. In this way, as a matter of classification, man appears in the latest Interglacial periods. This, however, as above stated, I regard as an error in arrangement; but it makes no practical difference as to the facts.

Inasmuch, however, as the human remains of the Post-glacial epoch are those of fully developed men of high type, it may be said, and has often been said, that man in some lower stage of development *must* have existed at a far earlier period. That is, he must, if certain theories as to his evolution from lower animals are to be sustained. This, however, is not a mode of reasoning in accordance with the methods of science. When facts fail to sustain certain theories we are usually in the habit of saying "so much the worse for the theories," not "so much the worse for the facts," or at least we claim the right to hold our judgment in suspense till some confirmatory facts are forthcoming.

We have now to inquire as to the actual nature of the indications of man in Europe and Western Asia at the close of the Glacial or Pleistocene period. These are principally such of his tools or weapons as could escape decay when embedded in river gravels, or in the earth and stalagmite of caverns or rock shelters, or buried with his bones in caves of sepulture. Very valuable accessory fossils are the broken bones of the animals he has used as food. Most valuable, and rarest of all, are well-preserved human skulls and skeletons. Some doubt may attach

to mere flint flakes, in the absence of other remains; but the other indications above referred to are indisputable, and when proper precautions are taken to notice the succession of beds, and to eliminate the effects of any later disturbance of the deposits, human fossils become as instructive and indisputable as any others.

When the whole of the facts thus available are put together, we find that the earliest men of whom we have osseous remains, and who, undoubtedly, inhabited Europe and Western Asia in the second continental period, before the establishment of the present geography, and before the disappearance of the mammoth and its companions, were of two races or subraces, agreeing in certain respects, differing in others. Both have long or dolichocephalic heads, and seem to have been men of great strength and muscular energy, with somewhat coarse countenances of Mongolian type, and they seem to have been of roving habits, living as hunters and fishermen in a semi-barbarous condition, but showing some artistic skill and taste in their carvings on bone and other ornaments.

The earliest of the two races locally, though, on the whole, they were contemporaneous, is that known as the Cannstadt or Neanderthal people, who are characterized by a low forehead, with beetling brows, massive limb bones and moderate stature. So far as known they were the ruder and less artistic of the two races. The other, the Engis or Cromagnon race, was of higher type, with well-formed and capacious skull, and a countenance which, if somewhat broad, with high cheek bones, eyes lengthened laterally, and heavy lower jaw, must have been of somewhat grand and impressive features. These men are of great stature, some examples being seven feet in height, and with massive bones, having strong muscular impressions. The Engis skull found in a cave in Belgium, with bones of the mammoth, the skeletons of the Cromagnon cave in the valley of the Vezere, in France, and those of the caves of Mentone, in Italy, repre-

sent this race. Doubts, it is true, have been entertained as to whether the last mentioned race is really palanthropic; but the latest facts as to their mode of occurrence and associations seem to render this certain. These men were certainly contemporaneous with the mammoth, and they disappeared in the cataclysm which closed the earlier anthropic period. Attempts have, however, been made to separate them into groups according to age, within this period;[1] and there can be no doubt that both in France and England the lower and older strata of gravels and caves yield ruder and less perfect implements than the higher. Independently, however, of the fact that the very earliest men may have been peaceful gatherers of fruit, and not hunters or warriors, having need of lethal weapons, such facts may rather testify to local improvement in the condition of certain tribes than to any change of race. Such local improvement would be very likely to occur wherever a new locality was taken possession of by a small and wandering tribe, which, in process of time, might increase in numbers and in wealth, as well as in means of intercourse with other tribes. A similar succession would occur when caves, used at first as temporary places of rendezvous by savage tribes, became afterwards places of residence, or were acquired by conquest on the part of tribes a little more advanced, in the manner in which such changes are constantly taking place in rude communities.

Yet on facts of this nature have been built extensive generalizations as to a race of river-drift men, in a low and savage condition, replaced, after the lapse of ages, by a people somewhat more advanced in the arts, and specially addicted to a cavern life; and this conclusion is extended to Europe and Asia, so that in every case where rude flint implements exist in river gravels, evidence is supposed to be found of the earlier of these races. But no physical break separates the two periods; the

[1] Mortillet, "Pre-historic Men."

fauna remained the same; the skulls, so far as known, present little difference; and even in works of art the distinction is invalidated by grave exceptions, which are intensified by the fact, which the writer has elsewhere illustrated, that in the case of the same people their residences in caves, etc., and their places of burial are likely to contain very different objects from those which they leave in river gravels.

It is admitted that the whole of these Palæocosmic men are racially distinct from modern men, though most nearly allied in physical characters to some of the Mongoloid races of the northern regions. Some of their characters also appear in the native races of America, and occasional cases occur, when even the characters of the Cannstadt skull reappear in modern times. The skull of the great Scottish king Robert Bruce was of this type; and his indomitable energy and governing power may have been connected with this fact. Attempts have even been made[1] to show an intimate connection between the cave men and the Esquimaux of Greenland and Arctic America, but, as Wilson has well shown,[2] this is not borne out by their cranial characters, and the resemblances, such as they are, in arts and implements, are common to the Esquimaux and many other American tribes. In many respects, however, the arts and mode of life, as well as some of the physical characters of the Palæocosmic men of Europe were near akin to those of the ruder native races of America.

Perhaps one of the most curious examples of this is the cave at Sorde, in the western Pyrenees. On the floor of this cave lay a human skeleton, covered with fallen blocks of stone. With it were found forty canine teeth of the bear, and three of the lion, perforated for suspension, and several of these teeth are skilfully engraved with figures of animals, one bearing the engraved figure of an embroidered glove. This necklace, no

[1] Dawkins, "Early Man in Britain."

[2] Address to Anthropological section of the American Association, 1882.

doubt just such a trophy of the chase as would now be worn by a red Indian hunter, though more elaborate, must have belonged to the owner of the skull, who would appear to have perished by a fall of rock, or to have had his body covered after death with stones. In the deposit near and under these remains were flint flakes. Above the skull were several feet of refuse, stones, and bones of the horse, reindeer, etc., and "Paleolithic" flint implements, and above all were placed the remains of thirty skulls and skeletons with beautifully chipped flint implements, some of them as fine as any of later age. After the burial of these the cave seems to have been finally closed with large stones. The French explorers of this cave refer the lower and upper skulls to the same race, that of Cromagnon; but others consider the upper remains as "Neolithic," though there is no reason why a man who possessed a necklace of beautifully carved teeth should not have belonged to a tribe which used well-made stone implements, or why the weapons buried with the dead should have been no better than the chips and flakes left by the same people in their rubbish heaps. In any case the interment—and this applies also to the Mentone caves—recalls the habits of American aborigines. In some of these cases we have even deposits of red oxide of iron, representing the war paint of the ancient hunter.

Widely different opinions have been held by archæologists as to the connection of the Palanthropic and Neanthropic ages. It suits the present evolutionist and exaggerated uniformitarianism of our day to take for granted that the two are continuous, and pass into each other. But there are stubborn facts against this conclusion. Let us take, for example, the area represented by the British Islands and the neighbouring continent. In the earlier period Britain was a part of the mainland, and was occupied by the mammoth, the woolly rhinoceros, and other animals, now locally or wholly extinct. The human inhabitants were of a large-bodied and coarse race not now found

anywhere. In the later period all this is changed. Britain has become an island. Its gigantic Post-glacial fauna has disappeared. Its human inhabitants are now small in stature and delicate in feature, and represented to this day by parts of the population of the south of Wales and Ireland. They buried their dead in the peculiar cemeteries known as long barrows, and their implements and weapons are of a new type, previously unknown. All this shows a great interval of physical and organic mutation. In connection with this we have the high-level gravel and rubble, which Prestwich has shown to belong to this stage, and which proves a subsidence even greater than that to be inferred from the present diminution of the land area. Knowing as we do that the close of the Glacial period was not more than 8,000 years ago, and deducting from this the probable duration of the Palanthropic age on the one hand, and that of modern history on the other, we must admit that the interval left for the great physical and faunal changes above referred to is too small to permit them to have occurred as the result of slow and gradual operations. Considerations of this kind have indeed some of the best authorities on the subject, as Cartailhac, Forel, and de Mortillet, to hold that there is "an immense space, a great gap, during which the fauna was renewed, and after which a new race of men suddenly made its appearance, and polished stone instead of chipping it, and surrounded themselves with domestic animals."[1] There is thus, in the geological history of man an interval of physical and organic change, corresponding to that traditional and historical deluge which has left its memory with all the more ancient nations. Thus our men of the Palanthropic, Post-glacial or Mammoth age are the same we have been accustomed to call Antediluvians, and their immediate successors are identical with the Basques

[1] Quatrefages, "The Human Species." The interval should not, however, be placed after the reindeer period, as this animal occurs in both ages.

and ancient Iberians, a non-Aryan or Turanian people who once possessed nearly the whole of Europe, and included the rude Ugrians and Laps of the north, the civilized Etruscans of the south, and the Iberians of the west, with allied tribes occupying the British Islands. This race, scattered and overthrown before the dawn of authentic history in Europe by the Celts and other intrusive peoples, was unquestionably that which succeeded the now extinct Palæocosmic race, and constituted the men of the so-called "Neolithic period," which thus connects itself with the modern history of Europe, from which it is not separated by any physical catastrophe like that which divides the older men of the mammoth age and the widely spread continents of the Post-glacial period from our modern days. This identification of the Neolithic men with the Iberians, which the writer has also insisted on, Dawkins deserves credit for fully elucidating, and he might have carried it farther, to the identification of these same Iberians with the Berbers, the Guanches of the Canary Islands, and the Caribbean and other tribes of eastern and central America. On these hitherto dark subjects light is now rapidly breaking, and we may hope that much of the present obscurity will soon be cleared away.

Supposing, then, that we may apply the term Anthropic to that portion of the Kainozoic period which intervenes between the close of the Glacial age and the present time, and that we admit the division of this into two portions, the earlier, called the Palanthropic, and the later, which still continues, the Neanthropic, it will follow that one great physical and organic break separates the Palanthropic age from the preceding Glacial, and a second similar break separates the two divisions of the Anthropic from each other. This being settled, if we allow say 2,500 years from the Glacial age for the first peopling of the world and the Palanthropic age, and if we consider the modern history of the European region and the adjoining parts of Asia

and Africa to go back for 5,000 years, there will remain a space of from 500 to 1,000 years for the destruction of the Palæocosmic men and the re-peopling of the old continent by such survivors as founded the Neocosmic peoples. These later peoples, though distinct racially from their predecessors, may represent a race contemporary with them in some regions in which it was possible to survive the great cataclysm, so that we do not need to ask for time to develop such new race.[1]

We cannot but feel some regret that the grand old Palæocosmic race was destined to be swept away by the flood, but it was no doubt better for the world that it should be replaced by a more refined if feebler race. When we see how this has, in some of its forms, reverted to the old type, and emulated, if not surpassed it in filling the earth with violence, we may, perhaps, congratulate ourselves on the extinction of the giant races of the olden time.

REFERENCES:—"Fossil Men," London, 1880. The Antiquity of Man, *Princeton Review*. "Pre-historic Man in Egypt and the Lebanon," Trans. Vict. Institute, 1884. Pre-historic Times in Egypt and Palestine, *North American Review*, June and July, 1892.

[1] For details of the physical characters of the older races of men I may refer to the works mentioned below, or to the writings of Dawkins and Quatrefages.

MAN IN NATURE.

DEDICATED TO THE MEMORY OF

MY DEAR FRIEND DR. P. P. CARPENTER,

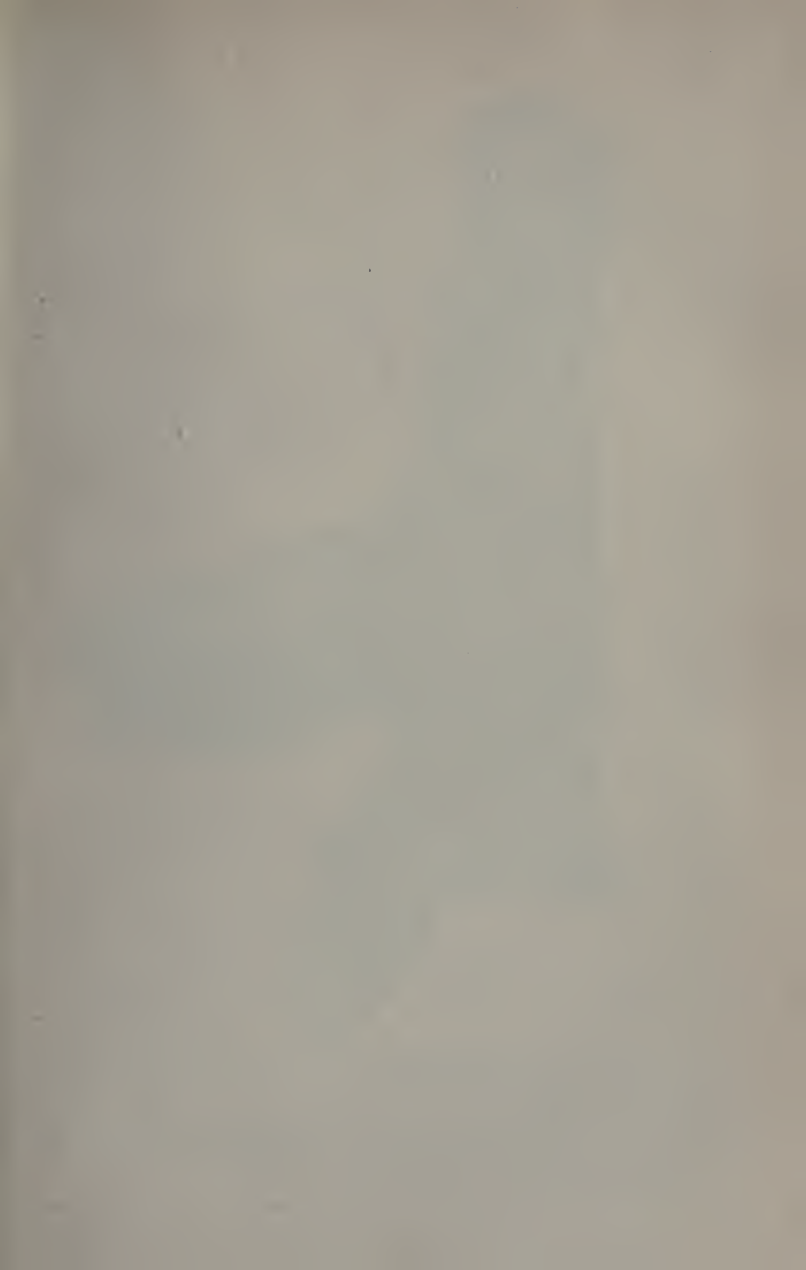
AT ONCE AN EMINENT NATURALIST AND

EDUCATOR—

EQUALLY A LOVER OF NATURE,

OF HIS FELLOW MEN AND OF GOD.

What is Nature—Man a part of Nature—Distinction between Man and other Animals—Man as an Imitator of Nature—Man as at War with Nature—Man in Harmony with Nature





CARVING OF THE PALANTHROPIC AGE.—Cave of Mas d'Azil, France; after Cartailhac.

Heads of the wild horse, carved on antler of the reindeer, and showing accurate imitation of nature, with ideal and adaptive art on the part of the antediluvian sculptor. (See p. 490.)

CHAPTER XVIII.

MAN IN NATURE.

FEW words are used among us more loosely than "nature." Sometimes it stands for the material universe as a whole. Sometimes it is personified as a sort of goddess, working her own sweet will with material things. Sometimes it expresses the forces which act on matter, and again it stands for material things themselves. It is spoken of as subject to law, but just as often natural law is referred to in terms which imply that nature itself is the lawgiver. It is supposed to be opposed to the equally vague term "supernatural"; but this term is used not merely to denote things above and beyond nature, if there are such, but certain opinions held respecting natural things. On the other hand, the natural is contrasted with the artificial, though this is always the outcome of natural powers, and is certainly not supernatural. Again, it is applied to the inherent properties of beings for which we are unable to account, and which we are content to say constitute their nature. We cannot look into the works of any of the more speculative writers of the day without meeting with all these uses of the word, and have to be constantly on our guard lest by a change of its meaning we shall be led to assent to some proposition altogether unfounded.

For illustrations of this convenient though dangerous ambiguity, I may turn at random to almost any page in Darwin's celebrated work on the "Origin of Species." In the beginning of Chapter III. he speaks of animals "in a state of nature"

that is, not in a domesticated or artificial condition, so that here nature is opposed to the devices of man. Then he speaks of species as "arising in nature," that is, spontaneously produced in the midst of certain external conditions or environment outside of the organic world. A little farther on he speaks of useful varieties as given to man by "the hand of Nature," which here becomes an imaginary person; and it is worthy of notice that in this place the printer or proof-reader has given the word an initial capital, as if a proper name. In the next section he speaks of the "works of Nature" as superior to those of art. Here the word is not only opposed to the artificial, but seems to imply some power above material things and comparable with or excelling the contriving intelligence of man. I do not mean by these examples to imply that Darwin is in this respect more inaccurate than other writers. On the contrary, he is greatly surpassed by many of his contemporaries in the varied and fantastic uses of this versatile word. An illustration which occurs to me here, as at once amusing and instructive, is an expression used by Romanes, one of the cleverest of the followers of the great evolutionist, and which appears to him to give a satisfactory explanation of the mystery of elevation in nature. He says, "Nature selects the best individuals out of each generation to live." Here nature must be an intelligent agent, or the statement is simply nonsensical. The same alternative applies to much of the use of the favourite term "natural selection." In short, those who use such modes of expression would be more consistent if they were at once to come back to the definition of Seneca, that nature is "a certain divine purpose manifested in the world."

The derivation of the word gives us the idea of something produced or becoming, and it is curious that the Greek *physis*, though etymologically distinct, conveys the same meaning—a coincidence which may perhaps lead us to a safe and serviceable definition. Nature, rightly understood, is, in short, an

orderly system of things in time and space, and this not invariable, but in a state of constant movement and progress, whereby it is always becoming something different from what it was. Now man is placed in the midst of this orderly, law-regulated yet ever progressive system, and is himself a part of it; and if we can understand his real relations to its other parts, we shall have made some approximation to a true philosophy. The subject has been often discussed, but is perhaps not yet quite exhausted.[1]

Regarding man as a part of nature, we must hold to his entering into the grand unity of the natural system, and must not set up imaginary antagonisms between man and nature as if he were outside of it. An instance of this appears in Tyndall's celebrated Belfast address, where he says, in explanation of the errors of certain of the older philosophers, that "the experiences which formed the weft and woof of their theories were chosen not from the study of nature, but from that which lay much nearer to them—the observation of Man": a statement this which would make man a supernatural, or at least a preternatural being. Again, it does not follow, because man is a part of nature, that he must be precisely on a level with its other parts. There are in nature many planes of existence, and man is no doubt on one of its higher planes, and possesses distinguishing powers and properties of his own. Nature, like a perfect organism, is not all eye or all hand, but includes various organs, and so far as we see it in our planet, man is its head, though we can easily conceive that there may be higher beings in other parts of the universe beyond our ken.

The view which we may take of man's position relatively to the beings which are nearest to him, namely, the lower animals, will depend on our point of sight—whether that of mere anatomy

[1] "Man's Place in Nature," *Princeton Review*, November, 1878. "The Unity of Nature," by the Duke of Argyll, 1884, may be considered as suggestive of the thoughts of this chapter.

and physiology, or that of psychology and pneumatology as well. This distinction is the more important, since, under the somewhat delusive term "biology," it has been customary to mix up all these considerations, while, on the other hand, those anatomists who regard all the functions of organic beings as merely mechanical and physical, do not scruple to employ this term biology for their science, though on their hypothesis there can be no such thing as life, and consequently the use of the word by them must be either superstitious or hypocritical.

Anatomically considered, man is an animal of the class *Mammalia*. In that class, notwithstanding the heroic efforts of some modern detractors from his dignity to place him with the monkeys in the order *Primates*, he undoubtedly belongs to a distinct order. I have elsewhere argued that, if he were an extinct animal, the study of the bones of his hand, or of his head, would suffice to convince any competent palæontologist that he represents a distinct order, as far apart from the highest apes as they are from the carnivora. That he belongs to a distinct family no anatomist denies, and the same unanimity of course obtains as to his generic and specific distinctness. On the other hand, no zoological systematist now doubts that all the races of men are specifically identical. Thus we have the anatomical position of man firmly fixed in the system of nature, and he must be content to acknowledge his kinship not only with the higher animals nearest to him, but with the humblest animalcule. With all he shares a common material and many common features of structure.

When we ascend to the somewhat higher plane of physiology we find in a general way the same relationship to animals. Of the four grand leading functions of the animal, nutrition, reproduction, voluntary motion, and sensation, all are performed by man as by other animals. Here, however, there are some marked divergences connected with special anatomical structures, on the one hand, and with his higher endowments on the

other. With regard to food, for example, man might be supposed to be limited by his masticatory and digestive apparatus to succulent vegetable substances. But by virtue of his inventive faculties he is practically unlimited, being able by artificial processes to adapt the whole range of vegetable and animal food substances to his use. He is very poorly furnished with natural tools to aid in procuring food, as claws, tusks, etc., but by invented implements he can practically surpass all other creatures. The long time of helplessness in infancy, while it is necessary for the development of his powers, is a practical disadvantage which leads to many social arrangements and contrivances specially characteristic of man. Man's sensory powers, while inferior in range to those of many other animals, are remarkable for balance and completeness, leading to perceptions of differences in colours, sounds, etc., which lie at the foundation of art. The specialization of the hand again connects itself with contrivances which render an animal naturally defenceless the most formidable of all, and an animal naturally gifted with indifferent locomotive powers able to outstrip all others in speed and range of locomotion. Thus the physiological endowments of man, while common to him with other animals, and in some respects inferior to theirs, present in combination with his higher powers points of difference which lead to the most special and unexpected results.

In his psychical relations, using this term in its narrower sense, we may see still greater divergencies from the line of the lower animals. These may no doubt be connected with his greater volume of brain ; but recent researches seem to show that brain has more to do with motory and sensory powers than with those that are intellectual, and thus, that a larger brain is only indirectly connected with higher mental manifestations. Even in the lower animals it is clear that the ferocity of the tiger, the constructive instinct of the beaver, and the sagacity of the elephant depend on psychical powers which

are beyond the reach of the anatomist's knife, and this is still more markedly the case in man. Following in part the ingenious analysis of Mivart, we may regard the psychical powers of man as reflex, instinctive, emotional, and intellectual; and in each of these aspects we shall find points of resemblance to other animals, and of divergence from them. In regard to reflex actions, or those which are merely automatic, inasmuch as they are intended to provide for certain important functions without thought or volition, their development is naturally in the inverse ratio of psychical elevation, and man is consequently, in this respect, in no way superior to lower animals. The same may be said with reference to instinctive powers, which provide often for complex actions in a spontaneous and unreasoning manner. In these also man is rather deficient than otherwise; and since, from their nature, they limit their possessors to narrow ranges of activity, and fix them within a definite scope of experience and efficiency, they would be incompatible with those higher and more versatile inventive powers which man possesses. The comb-building instinct of the bee, the nest-weaving instinct of the bird, are fixed and invariable things, obviously incompatible with the varied contrivance of man; and while instinct is perfect within its narrow range, it cannot rise beyond this into the sphere of unlimited thought and contrivance. Higher than mere instinct are the powers of imagination, memory, and association, and here man at once steps beyond his animal associates, and develops these in such a variety of ways, that even the rudest tribes of men, who often appear to trust more to these endowments than to higher powers, rise into a plane immeasurably above that of the highest and most intelligent brutes, and toward which they are unable, except to a very limited degree, to raise those of the more domesticable animals which they endeavour to train into companionship with themselves. It is, however, in these domesticated animals that we find the highest degree of approx-

imation to ourselves in emotional development, and this is perhaps one of the points that fits them for such human association. In approaching the higher psychical endowments, the affinity of man and the brute appears to diminish and at length to cease, and it is left to him alone to rise into the domain of the rational and ethical.

Those supreme endowments of man we may, following the nomenclature of ancient philosophy and of our Sacred Scriptures, call "pneumatical" or spiritual. They consist of consciousness, reason, and moral volition. That man possesses these powers every one knows; that they exist or can be developed in lower animals no one has succeeded in proving. Here, at length, we have a severance between man and material nature. Yet it does not divorce him from the unity of nature, except on the principles of atheism. For if it separates him from animals, it allies him with the Power who made and planned the animals. To the naturalist the fact that such capacities exist in a being who in his anatomical structure so closely resembles the lower animals, constitutes an evidence of the independent existence of those powers and of their spiritual character and relation to a higher power which, I think, no metaphysical reasoning or materialistic scepticism will suffice to invalidate. It would be presumption, however, from the standpoint of the naturalist to discuss at length the powers of man's spiritual being. I may refer merely to a few points which illustrate at once his connection with other creatures, and his superiority to them as a higher member of nature.

And, first, we may notice those axiomatic beliefs which lie at the foundation of human reasoning, and which, while apparently in harmony with nature, do not admit of verification except by an experience impossible to finite beings. Whether these are ultimate truths, or merely results of the constitution bestowed on us, or effects of the direct action of the creative mind on ours, they are to us like the instincts of animals—in-

fallible and unchanging. Yet, just as the instincts of animals unfailingly connect them with their surroundings, our intuitive beliefs fit us for understanding nature and for existing in it as our environment. These beliefs also serve to connect man with his fellow man, and in this aspect we may associate with them those universal ideas of right and wrong, of immortality, and of powers above ourselves, which pervade humanity.

Another phase of this spiritual constitution is illustrated by the ways in which man, starting from powers and contrivances common to him and animals, develops them into new and higher uses and results. This is markedly seen in the gift of speech. Man, like other animals, has certain natural utterances expressive of emotions or feelings. He can also, like some of them, imitate the sounds produced by animate or inanimate objects; while the constitution of his brain and vocal organs gives him special advantages for articulate utterance. But when he develops these gifts into a system of speech expressing not mere sounds occurring in nature, but by association and analogy with these, properties and relations of objects and general and abstract ideas, he rises into the higher sphere of the spiritual. He thus elevates a power of utterance common to him with animals to a higher plane, and connecting it with his capacity for understanding nature and arriving at general truths, asserts his kinship to the great creative mind, and furnishes a link of connection between the material universe and the spiritual Creator.

The manner of existence of man in nature is as well illustrated by his arts and inventions as by anything else; and these serve also to enlighten us as to the distinction between the natural and the artificial. Naturalists often represent man as dependent on nature for the first hints of his useful arts. There are in animal nature tailors, weavers, masons, potters, carpenters, miners, and sailors, independently of man, and many of the tools, implements, and machines which he is said

to have invented were perfected in the structures of lower animals long before he came into existence. In all these things man has been an assiduous learner from nature, though in some of them, as for example in the art of aërial navigation, he has striven in vain to imitate the powers possessed by other animals. But it may well be doubted whether man is in this respect so much an imitator as has been supposed, and whether the resemblance of his plans to those previously realized in nature does not depend on that general fitness of things which suggests to rational minds similar means to secure similar ends. But in saying this we in effect say that man is not only a part of nature, but that his mind is in harmony with the plans of nature, or, in other words, with the methods of the creative mind. Man is also curiously in harmony with external nature in the combination in his works of the ideas of plan and adaptation, of ornament and use. In architecture, for example, devising certain styles or orders, and these for the most part based on imitations of natural things; he adapts these to his ends, just as in nature types of structure are adapted to a great variety of uses, and he strives to combine, as in nature, perfect adaptation to use with conformity to type or style. So, in his attempts at ornament he copies natural forms, and uses these forms to decorate or conceal parts intended to serve essential purposes in the structure. This is at least the case in the purer styles of construction. It is in the more debased styles that arches, columns, triglyphs, or buttresses are placed where they can serve no useful purpose, and become mere excrescences. But in this case the abnormality resulting breeds in the beholder an unpleasing mental confusion, and causes him, even when he is unable to trace his feelings to their source, to be dissatisfied with the result. Thus man is in harmony with that arrangement of nature which causes every ornamental part to serve some use, and which unites adaptation with plan.

The following of nature must also form the basis of those fine arts which are not necessarily connected with any utility, and in man's pursuit of art of this kind we see one of the most recondite and at first sight inexplicable of his correspondences with the other parts of nature ; for there is no other creature that pursues art for its own sake. Modern archæological discovery has shown that the art of sculpture began with the oldest known races of man, and that they succeeded in producing very accurate imitations of natural objects. But from this primitive starting-point two ways diverge. One leads to the conventional and the grotesque, and this course has been followed by many semi-civilized nations. Another leads to accurate imitation of nature, along with new combinations arising from the play of intellect and imagination. Let us look for a moment at the actual result of the development of these diverse styles of art, and at their effect on the culture of humanity as existing in nature. We may imagine a people who have wholly discarded nature in their art, and have devoted themselves to the monstrous and the grotesque. Such a people, so far as art is concerned, separates itself widely from nature and from the mind of the Creator, and its taste and possibly its morals sink to the level of the monsters it produces. Again, we may imagine a people in all respects following nature in a literal and servile manner. Such a people would probably attain to but a very moderate amount of culture, but having a good foundation, it might ultimately build up higher things. Lastly, we may fancy a people who, like the old Greeks, strove to add to the copying of nature a higher and ideal beauty by combining in one the best features of many natural objects, or devising new combinations not found in nature itself. In the first of these conditions of art we have a falling away from or caricaturing of the beauty of nature. In the second we have merely a pupilage to nature. In the third we find man aiming to be himself a creator, but basing his

creations on what nature has given him. Thus all art worthy of the name is really a development of nature. It is true the eccentricities of art and fashion are so erratic that they may often seem to have no law. Yet they are all under the rule of nature; and hence even uninstructed common-sense, unless dulled by long familiarity, detects in some degree their incongruity, and though it may be amused for a time, at length becomes wearied with the mental irritation and nervous disquiet which they produce.

I may be permitted to add that all this applies with still greater force to systems of science and philosophy. Ultimately these must be all tested by the verities of nature to which man necessarily submits his intellect, and he who builds for aye must build on the solid ground of nature. The natural environment presents itself in this connection as an educator of man. From the moment when infancy begins to exercise its senses on the objects around, this education begins—training the powers of observation and comparison, cultivating the conception of the grand and beautiful, leading to analysis and abstract and general ideas. Left to itself, it is true this natural education extends but a little way, and ordinarily it becomes obscured or crushed by the demands of a hard utility, or by an artificial literary culture, or by the habitude of monstrosity and unfitness in art. Yet, when rightly directed, it is capable of becoming an instrument of the highest culture, intellectual, æsthetic, and even moral. A rational system of education would follow nature in the education of the young, and drop much that is arbitrary and artificial. Here I would merely remark, that when we find that the accurate and systematic study of nature trains most effectually some of the more practical powers of mind, and leads to the highest development of taste for beauty in art, we see in this relation the unity of man and nature, and the unity of both with something higher than either.

It may, however, occur to us here, that when we consider man as an improver and innovator in the world, there is much that suggests a contrariety between him and nature, and that, instead of being the pupil of his environment, he becomes its tyrant. In this aspect man, and especially civilized man, appears as the enemy of wild nature, so that in those districts which he has most fully subdued, many animals and plants have been exterminated, and nearly the whole surface has come under his processes of culture, and has lost the characteristics which belonged to it in its primitive state. Nay more, we find that by certain kinds of so-called culture man tends to exhaust and impoverish the soil, so that it ceases to minister to his comfortable support, and becomes a desert. Vast regions of the earth are in this impoverished condition, and the westward march of exhaustion warns us that the time may come when even in comparatively new countries, like America, the land will cease to be able to sustain its inhabitants. Behind this stands a still farther and portentous possibility. The resources of chemistry are now being taxed to the utmost to discover methods by which the materials of human food may be produced synthetically, and we may possibly, at some future time, find that albumen and starch may be manufactured cheaply from their elements by artificial processes. Such a discovery might render man independent of the animal and vegetable kingdoms. Agriculture might become an unnecessary and unprofitable art. A time might come when it would no longer be possible to find on earth a green field, or a wild animal; and when the whole earth would be one great factory, in which toiling millions were producing all the materials of food, clothing, and shelter. Such a world may never exist, but its possible existence may be imagined, and its contemplation brings vividly before us the vast powers inherent in man as a subverter of the ordinary course of nature. Yet even this ultimate annulling of wild nature would be brought about not by any-

thing preternatural in man, but simply by his placing himself in alliance with certain natural powers and agencies, and by their means attaining dominion over the rest.

Here there rises before us a spectre which science and philosophy appear afraid to face, and which asks the dread question,—What is the cause of the apparent abnormality in the relations of man and nature? In attempting to solve this question, we must admit that the position of man, even here, is not without natural analogies. The stronger preys upon the weaker, the lower form gives place to the higher, and in the progress of geological time old species have died out in favour of newer, and old forms of life have been exterminated by later successors. Man, as the newest and highest of all, has thus the natural right to subdue and rule the world. Yet there can be little doubt that he uses this right unwisely and cruelly, and these terms themselves explain why he does so, because they imply freedom of will. Given a system of nature destitute of any being higher than the instinctive animal, and introduce into it a free rational agent, and you have at once an element of instability. So long as his free thought and purpose continue in harmony with the arrangements of his environment, so long all will be harmonious; but the very hypothesis of freedom implies that he can act otherwise, and so perfect is the equilibrium of existing things, that one wrong or unwise action may unsettle the nice balance, and set in operation trains of causes and effects producing continued and ever-increasing disturbance. Thus the most primitive state of man, though destitute of all mechanical inventions, may have been better in relation to the other parts of nature than any that he has subsequently attained to. His "many inventions" have injured him in his natural relations. This "fall of man" we know as a matter of observation and experience has actually occurred, and it can be retrieved only by casting man back again into

the circle of merely instinctive action, or by carrying him forward until, by growth in wisdom and knowledge, he becomes fitted to be the lord of creation. The first method has been proved unsuccessful by the rebound of humanity against all the attempts to curb and suppress its liberty. The second has been the effort of all reformers and philanthropists since the world began, and its imperfect success affords a strong ground for clinging to the theistic view of nature, for soliciting the intervention of a Power higher than man, and for hoping for a final restitution of all things through the intervention of that Power. Mere materialistic evolution must ever and necessarily fail to account for the higher nature of man, and also for his moral aberrations. These only come rationally into the system of nature under the supposition of a Higher Intelligence, from whom man emanates, and whose nature he shares.

But on this theistic view we are introduced to a kind of unity and of evolution for a future age, which is the great topic of revelation, and is not unknown to science and philosophy, in connection with the law of progress and development deducible from the geological history, in which an ascending series of lower animals culminates in man himself. Why should there not be a new and higher plane of existence to be attained to by humanity—a new geological period, so to speak, in which present anomalies shall be corrected, and the grand unity of the universe and its harmony with its Maker fully restored. This is what Paul anticipates when he tells us of a "pneumatical" or spiritual body, to succeed to the present natural or "psychical" one, or what Jesus Himself tells us when He says that in the future state we shall be like to the angels. Angels are not known to us as objects of scientific observation, but such an order of beings is quite conceivable, and this not as supernatural, but as part of the order of nature. They are created beings like ourselves,

subject to the laws of the universe, yet free and intelligent and liable to error, in bodily constitution freed from many of the limitations imposed on us, mentally having higher range and grasp, and consequently masters of natural powers not under our control. In short, we have here pictured to us an order of beings forming a part of nature, yet in their powers as miraculous to us as we might be supposed to be to lower animals, could they think of such things. This idea of angels bridges over the great natural gulf between humanity and deity, and illustrates a higher plane than that of man in his present state, but attainable in the future. Dim perceptions of this would seem to constitute the substratum of the ideas of the so-called polytheistic religions. Christianity itself is in this aspect not so much a revelation of the supernatural as the highest bond of the great unity of nature. It reveals to us the perfect Man, who is also one with God, and the mission of this Divine Man to restore the harmonies of God and humanity, and consequently also of man with his natural environment in this world, and with his spiritual environment in the higher world of the future. If it is true that nature now groans because of man's depravity, and that man himself shares in the evils of this disharmony with nature around him, it is clear that if man could be restored to his true place in nature he would be restored to happiness and to harmony with God, and if, on the other hand, he can be restored to harmony with God, he will then be restored also to harmony with his natural environment, and so to life and happiness and immortality. It is here that the old story of Eden, and the teaching of Christ, and the prophecy of the New Jerusalem strike the same note which all material nature gives forth when we interrogate it respecting its relations to man. The profound manner in which these truths appear in the teaching of Christ has perhaps not been appreciated as it should, because we have not sought in that teaching the

philosophy of nature which it contains. When He points to the common weeds of the fields, and asks us to consider the garments more gorgeous than those of kings in which God has clothed them, and when He says of these same wild flowers, so daintily made by the Supreme Artificer, that to-day they are, and to-morrow are cast into the oven, He gives us not merely a lesson of faith, but a deep insight into that want of unison which, centring in humanity, reaches all the way from the wild flower to the God who made it, and requires for its rectification nothing less than the breathing of that Divine Spirit which first evoked order and life out of primeval chaos.

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